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GREEN BAY PHYTOPLANKTON
COMPOSITION, ABUNDANCE,
AND DISTRIBUTION

by

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FOREWORD

The Great Lakes National Program Office (GLNPO) of the United States Environmental Protection Agency was established in Region V, Chicago to focus attention on the significant and complex natural resource represented by the Great Lakes.

GLNPO implements a multi-media environmental management program drawing on a wide range of expertise represented by Universities, private firms, State, Federal, and Canadian Governmental Agencies and the International Joint Commission. The goal of the GLNPO program is to develop programs, practices and technology necessary for a better understanding of the Great Lakes Basin Ecosystem and to eliminate or reduce to the maximum extent practicable the discharge of pollutants into the Great Lakes system. The Office also coordinates U.S. actions in fulfillment of the Agreement between Canada and the United States of America on Great Lakes Water Quality of 1978.

This study was supported by a GLNPO grant to the University of Michigan at Ann Arbor for investigating the phytoplankton assemblages of northern Green Bay.

ABSTRACT

This project was initiated to evaluate the water quality of northern Green Bay on the basis of physicochemical and phytoplankton data. Emphasis was placed upon the interpretation of phytoplankton population spatial distributions and the diversity and dissimilarities of community composition with respect to the physicochemical qualities of the water.

Green Bay phytoplankton assemblages were characterized by high abundances and domination by taxa indicative of nutrient rich conditions. The most significant components of the communities were diatoms ad cryptomonads in May and blue-green algae in August and October. *Anacystis incerta*, *Rhodomonas minuta*, microflagellates, *Gloeocystis planctonica*, and *Cyclotella comensis* were the most abundant taxa.

Two main regions of different water quality were determined by phytoplankton population and community analysis. These regions are approximately delineated as north and south of Chambers Island. Phytoplankton and physicochemical indications of eutrophication were generally greater in the southern region. Local evidence of more severe perturbation was noted in Little Bay de Noc near the Escanaba River and Escanaba, and near the Menominee River. More naturally eutrophic shallow water communities were found in Big Bay de Noc and along the northwest shore of Green Bay. Less eutrophic conditions along the Lake Michigan interface with Green Bay probably resulted from dilution of Green Bay water due to exchange with Lake Michigan water. Although the magnitude of this exchange cannot be quantitatively estimated from the results of the present investigation it must result in the export of nutrients and biological populations adapted to eutrophic conditions to Lake Michigan proper.

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INTRODUCTION

Green Bay, the largest bay of Lake Michigan, is one of the most culturally impacted areas in the upper Great Lakes. There is, however, much spatial and temporal variability in apparent water quality within the bay. The heavily loaded extreme southern tip of Green Bay contrasts with the somewhat naturally eutrophic waters of Big Bay de Noc and the clearer deeper water in the north-central portion of the bay.

This project was initiated by the United States Environmental Protection Agency, Region V, to document the water quality of Green Bay as suggested by physicochemical and phytoplankton data. This information is essential for management of the bay. Emphasis was placed upon interpretation of the phytoplankton population spatial distributions and the diversity and dissimilarities of the community compositions with respect to physicochemical conditions of the water. The sampling locations were located in northern Green Bay, the southernmost location being in the center of the bay east of the Oconto River.

Green Bay is an elongate body of water with a northeast to southwest longitudinal axis stretching 190 km from the Fox River in the south to Big Bay de Noc in the north and a mean width of about 35 km (Fig. 1). Depth maxima are over 60 m in the north-central part of the bay, with most depths less than 40 m and the complete western inshore area less than 20 m deep (Moore and Meyer, 1969).

The hydrodynamics of Green Bay are extremely variable and are generally controlled by geostrophic, wind and barometric forces. The bay's long, narrow, and relatively shallow morphometry enables considerable seiche

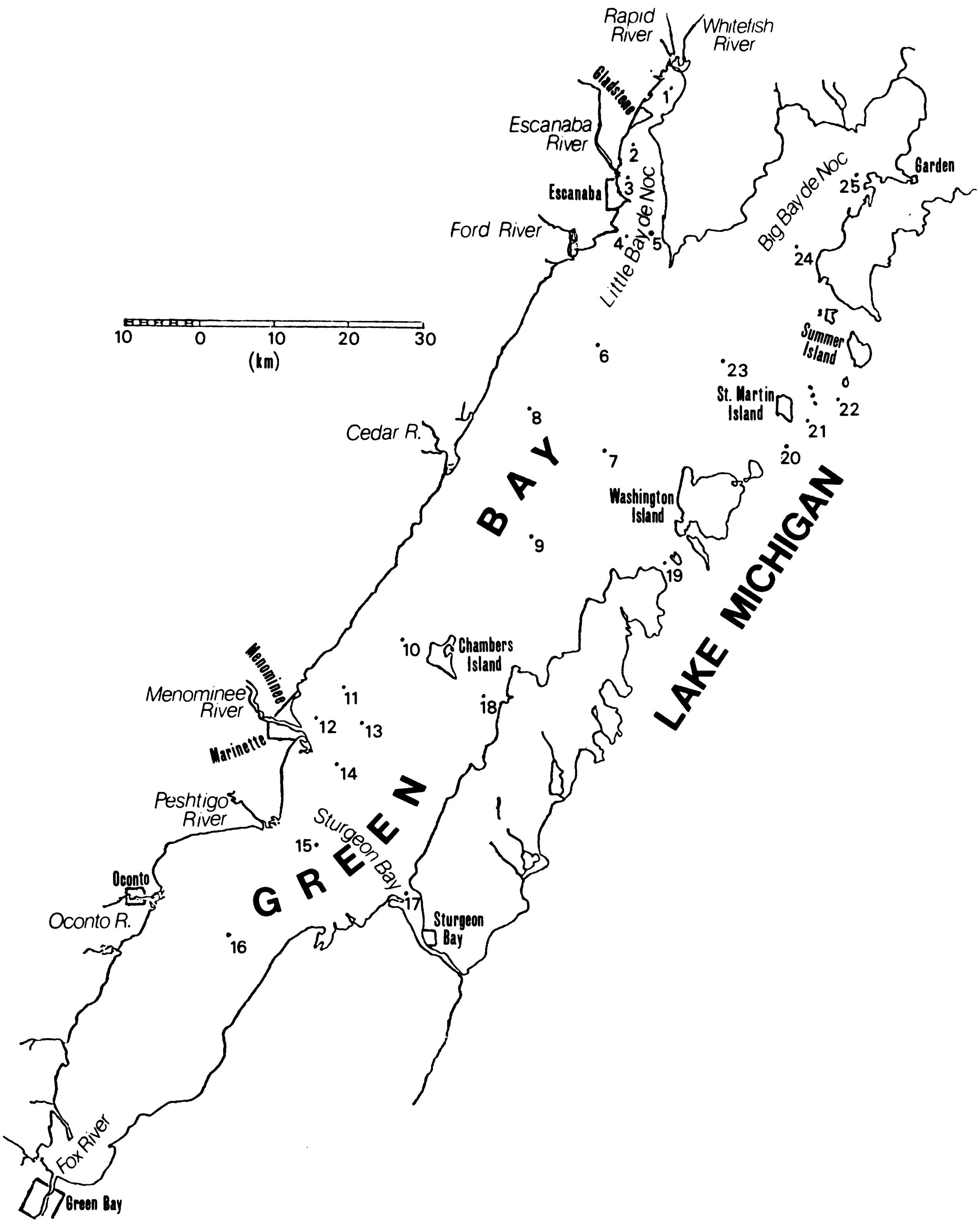

FIG. 1. The sampling locations and geography of Green Bay.

activity which enhances this variability and increases diffusivity of regional loading in the central bay. Currents in the bay tend to be counterclockwise with two main gyres separating the lower and upper reaches of the bay at a transect between the Menominee River and Sturgeon Bay. Fox River water concentration usually decreases to 25% 25 km from the river mouth (Ahrnsbrak, 1971) in the southern gyre, about 15 km south from our most southern sampling location.

Water movements in the northern gyre are not as well documented. They are susceptible to discontinuities due to exchange with Lake Michigan waters. Green Bay tends to have a relatively isolated water mass due to its limited and interrupted interface with Lake Michigan. However, substantial exchange may exist because the Bay de Noc complex alone has been estimated to contribute 13 X 10^3 kg PO_4^{-3}/yr. or 12% of the total PO_4^{-3} loaded to Lake Michigan (Upchurch, 1972). Water that does escape from the bay most commonly flows south along the Wisconsin shore. However, high conductivity values in north-central Lake Michigan have been attributed to Green Bay.

The Green Bay watershed comprises one third of all the land that drains into Lake Michigan. Nutrients, organic wastes, heavy metal ions, chlorinated pesticides, and PCBs flush into Green Bay from domestic, agricultural, and industrial sources in its watershed (Bertrand et al., 1976).

The most severe impact comes from Fox River loadings to southern Green Bay in the form of industrial and domestic wastes from about 1/2 million people and one of the largest pulp and paper industry complexes in the world along the lower Fox River. Pulp and paper mills are also located on the Oconto River, Peshtigo River, and Menominee River (Bertrand et al., 1976). Mill effluents are major sources of nutrients and oxygen-demanding compounds,

especially to the southern half of the bay. Domestic wastes are responsible for the moderate loading of these same contaminants into central and northern Green Bay with wastewater treatment plants discharging into the Escanaba and Menominee Rivers and Little Bay de Noc plus many other smaller sources around the bay (Tierney et al., 1976). Agricultural sources throughout the Green Bay watershed contribute animal wastes, chemical fertilizers, herbicides and pesticides.

The eutrophication of Green Bay has resulted from the nutrient and organic waste inputs. Schelske (1975) reports total soluble phosphorus loadings to Green Bay as 5.0 metric tons/day from the Fox, Oconto, Peshtigo, Menominee, Ford, Escanaba, Rapid, and Whitefish Rivers. Approximately 60% of this load enters the Green Bay basin via the Fox River. Schelske and Callender (1970) noted lower silica concentrations and transparency in Green Bay, especially in the extreme southern end, than in the rest of northern Lake Michigan. Howmiller and Beeton (1973) report O_2 depletion in the hypolimnion of southern Green Bay. The generally eutrophic conditions increase from north to south from southern loadings and east to west because of the general current pattern and the inherently nutrient rich, shallow western shore. It should be noted that spatial and temporal variations result from point source loadings and irregular hydrodynamics of this system.

Algal research has an intense history in Green Bay with a concentration in the south end. In southern Green Bay, Holland (1968,1969) studied the plankton diatoms, Industrial Bio-Test Laboratories, Inc. (Wisconsin Public Service Corp., 1974) studied phytoplankton and periphyton in relation to the Pulliam Power Plant, Adams and Stone (1973) studied *Cladophora glomerata* photosynthetic rates in relation to temperature, light, and Fox River inputs

and Sager (1971) and Patterson et al., (1975) examined phytoplankton assemblages in relation to Fox River loading. Vanderhoef et al., (1972,1974) took advantage of the eutrophic conditions and substantial blue-green algal populations of southern Green Bay to research phytoplankton nitrogen fixation. Holland and Claflin (1975) mapped the horizontal distribution of planktonic diatoms throughout the bay. Tierney et al. (1976) reported enumerations of phytoplankton samples from eight locations in central and northern Green Bay.

MATERIALS AND METHODS

Phytoplankton samples were collected from 25 locations in Green Bay (Fig. 1) in May, August, and October. In May, before thermal stratification, single composite-depth samples were collected at each location by Michigan Department of Natural Resources personnel. The composite type sampler was lowered to twice Secchi disc reading and raised to the surface. This sampler responds to increased water pressure, thus biasing the samples to deeper depths. The August and October samples were discrete and taken from near surface, near bottom, and usually one intermediate depth by U. S. EPA personnel. We received 25 samples from the May cruise, 70 samples from the August cruise and 73 samples from the October cruise.

Samples were preserved in Lugol's solution. Semi-permanent slides of the material were prepared by concentration of the material from 50 ml of water onto 25 mm "AA" Millipore filters, dehydration with a series of ethanol washes, and placement in clove oil on 50x70 mm glass slides. Prepared filters were covered with 43x50 mm #1 cover glasses and allowed to clear for

approximately four weeks. Any clove oil lost by volatilization was replaced and the edges of the cover glasses were sealed with paraffin.

Enumerations of the algal community were executed for all May samples and near surface and near bottom samples of August and October. A Leitz Ortholux microscope with a fluorite oil immersion objective giving about 1250X magnification and numerical aperature of 1.32 was used for counting. Population densities were determined as the average counts from two radial transects, corrected for volume. The raw counting data were coded for entry into computer files and subsequent analysis. Throughout this report, density refers to the number of algal units, whether cells or colonies, in a given volume of water.

Physicochemical water properties were measured by personnel of the agencies responsible for the field sampling and given to us. The May information is less complete compared to the August and October data. It should also be noted that May phytoplankton abundance estimates are not directly comparable to the other sampling periods because of the different sampling procedures used. Analysis of these samples was also limited by the fact that some of the samples were obviously decomposed when we received them. Even samples from sets which did not contain obvious fungal and bacterial growth are somewhat suspect in that some of the more delicate species may have been lost.

RESULTS

PHYSICOCHEMICAL CONDITIONS

Appendix A is a table of the physicochemical data.

[illegible]

May surface water temperatures varied from 2.3°C at locations near the Menominee River mouth May 3rd to 18.0 and 18.4°C at locations 17 and 18 in Sturgeon Bay and east of Chambers Island May 18th. May temperatures varied substantially but were generally higher in nearshore areas. August water temperatures ranged from the exceptional 10.0°C at location 17 in Sturgeon Bay to 22.5°C at location 7 in mid-bay west of Washington Island, and were usually about 20°C. October temperatures were lowest, 11.5°C, at location 1 in northern Little Bay de Noc and highest, 14.5°C, at locations 13, 14, 15, and 16 in the southern region of the sampled bay. Water temperatures were approximately the same throughout the bay.

pH.

May values varied from 7.8 to 8.9 with no distinct spatial patterns. August measurements ranged from 7.6 at location 17 in Sturgeon Bay to 8.6 along the Lake Michigan interface. October measurements ranged from 8.2 to 8.5. No areal patterns were recognized.

Alkalinity

No measurements accompanied the May phytoplankton samples. August surface values were generally 3-4 ppm CO_3 higher than October and were about 110 ppm CO_3. No spatial pattern was discernible.

Conductivity

May surface measurements were substantially greater and varied much more than those of August and October. Values ranged from 238 mohms at location 1 in northern Little Bay de Noc to 460 and 440 mohms at locations 17 and 18 in Sturgeon Bay and east of Chambers Island. Most other May measurements were between 300 and 400 mohms. August and October conductivity had a mean 275

mohms with most measurements within 10 mohms of the mean. August and October conductivity values gradually decreased from south to north.

Turbidity

No measurements accompanied the May phytoplankton samples. August surface turbidity was fairly uniform and generally 1.0 or less. October measurements were more variable and ranged from the unusually high 5.3 at location 1 in northern Little Bay de Noc to less than one at several scattered sampling locations surrounding St. Martin Island. October turbidity was somewhat lower in a band from Chambers Island to along the Lake Michigan interface.

Nitrate plus Nitrite

No measurements accompanied the May samples. August surface nitrate concentrations were very low south of Washington Island being 20 ppb except in Sturgeon Bay, and up to 100 ppb along the Lake Michigan interface. October nitrate values also generally decrease from north to south ranging from about 50 to 130 ppb. Low nitrate concentrations were noted at location 25 in Big Bay de Noc.

Ammonia

No measurements accompanied the May phytoplankton samples. August ammonia concentrations were about 4 ppb throughout most of the bay with much higher 40 and 50 ppb values in the vicinity of the Menominee River and a 150 ppb concentration near Escanaba. October values varied between 1 and 10 ppb throughout the bay with no apparent spatial patterns.

Silica

No measurements accompanied the May phytoplankton samples. August silica concentrations were 0.1 and 0.2 ppm throughout most of the bay except in northern Little Bay de Noc and Sturgeon Bay where values were about 1 and 2

ppm. October silica measured about 1.0 ppm along the Lake Michigan interface, increased in the northern bay to about 1.3 ppm, and dropped below 1.0 ppm south of Peshtigo River.

Secchi depth

May depths varied from 1.0 m in Little Bay de Noc to 6.0 m along the Lake Michigan interface. Secchi depths were generally substantially less in Little Bay de Noc and south of Chambers Island. August depths, between 2.5 and 5.5 m, were generally less south of Chambers Island. October depths averaged less than May and August, being from 1.5 to 4.0 m.

Summary of physicochemical conditions

Phosphorus concentrations were less than 2 ppb during August and October. May conditions delineated a region from Sturgeon Bay along the east coast of the bay to at least Chambers Island which included locations 17 and 18. Substantially higher conductivity values and water temperatures were noted here. These conditions were also observed in northern Big Bay de Noc at location 25. May Secchi depths were lower in Little Bay de Noc and south of Chambers Island than in the rest of the bay.

A slight consistent decrease in conductivity and a general increase of water transparency and SiO_2 and NO_3 concentrations from southern to northern Green Bay were observed in August. Comparatively low nutrient concentrations in an area of higher nutrient loading and low water transparencies usually indicate greater algal assimilation. This pattern was more weakly represented in October with the same south to north, but also a noticeable west to east, gradient. Low water transparencies but higher nutrient concentrations were the general October conditions in Little Bay de Noc.

The impacts of point source loading are difficult to detect when sampling

is done on as large a scale as this, but unusually high or low physicochemical measurements were common in Sturgeon Bay, in the Menominee River area, and near the Escanaba River and Escanaba in Little Bay de Noc. For example, in May the 2.3° C at location 12 by the Menominee demonstrated the cool spring runoff. Consistently low water transparency and generally lower pH characterized location 3 near the mouth of the Escanaba River. The high ammonia concentration at location 4 was suspected to be associated with the Escanaba wastewater treatment facility. The unusually high 40 and 50 ppb NH_3 concentrations at locations 13 and 14 were suspected impacts of the Menominee River loading that escaped detection at location 12, near the mouth.

PHYTOPLANKTON

The Green Bay phytoplankton assemblage comprised 400 algal taxa and about 80 genera from 8 divisions: Cyanophyta, Chlorophyta, Bacillariophyta, Chrysophyta, Cryptophyta, Pyrrophyta, Haptophyta, and Euglenophyta (Appendix B). The average density was 5293 cells/ml, with a range of 515 to 12,962 cells/ml. Due to severe deterioration of some of the May samples, only diatoms were counted for locations 8 and 17.

Community Analysis

Total Phytoplankton Distribution--

Only diatom densities are reported for May because of the previously discussed problems with sample decomposition. May diatom densities averaged about 400 cells/ml, with a range from 25 to 1070 cells (Appendix C). A transect of low diatom density was evident from location 16 to west of Chambers Island, and a region of high density paralleled that transect from Sturgeon Bay

to east of Chambers Island. Unusually high diatom densities of 871 and 1070 cells/ml were observed at location 25 in Big Bay de Noc and location 3 near the Escanaba River.

Surface phytoplankton averaged about 7500 cells/ml in August (Fig. 2), ranging from 2580 to 12,608 cells/ml. Assemblage densities usually decreased from south to north, but were highest at location 25 in Big Bay de Noc and lowest at location 2 in Little Bay de Noc and location 17 in Sturgeon Bay. August bottom densities, contrarily, showed an increase from the shallow western shore to the Lake Michigan interface. August bottom densities ranged from 1447 to 12,608 cells/ml, with a 4914 average. The deeper locations (7, 9, 19, and 20) had lower densities of about 2000 cells/ml, whereas northern Big Bay de Noc had the highest density of 12,608 cells/ml.

October surface communities (Fig. 2) averaged about 6800 cells/ml and ranged from 2584 to 12,862 cells/ml. Maximum density was observed at location 16 in southern Green Bay and a minimum at location 1 in Little Bay de Noc. Surface densities were generally lowest in the northcentral bay and along the Lake Michigan interface. High densities, 10,206 and 11,697 cells/ml, were noted at locations 24 and 25 in Big Bay de Noc. Bottom densities were lower, averaging 5432 cells/ml, ranging from 2817 to 8049 cells/ml. A general south to north and east to west decrease in density was observed. A corridor of low algal density extends from Little Bay de Noc to the Lake Michigan boundary. Overall August and October phytoplankton densities were about the same.

Species Diversity--

The Shannon-Weaver diversity index (Shannon and Weaver, 1963) was calculated for use as a community parameter. We have not intended to use it as a measure of Green Bay community stability. The use of species diversity as a

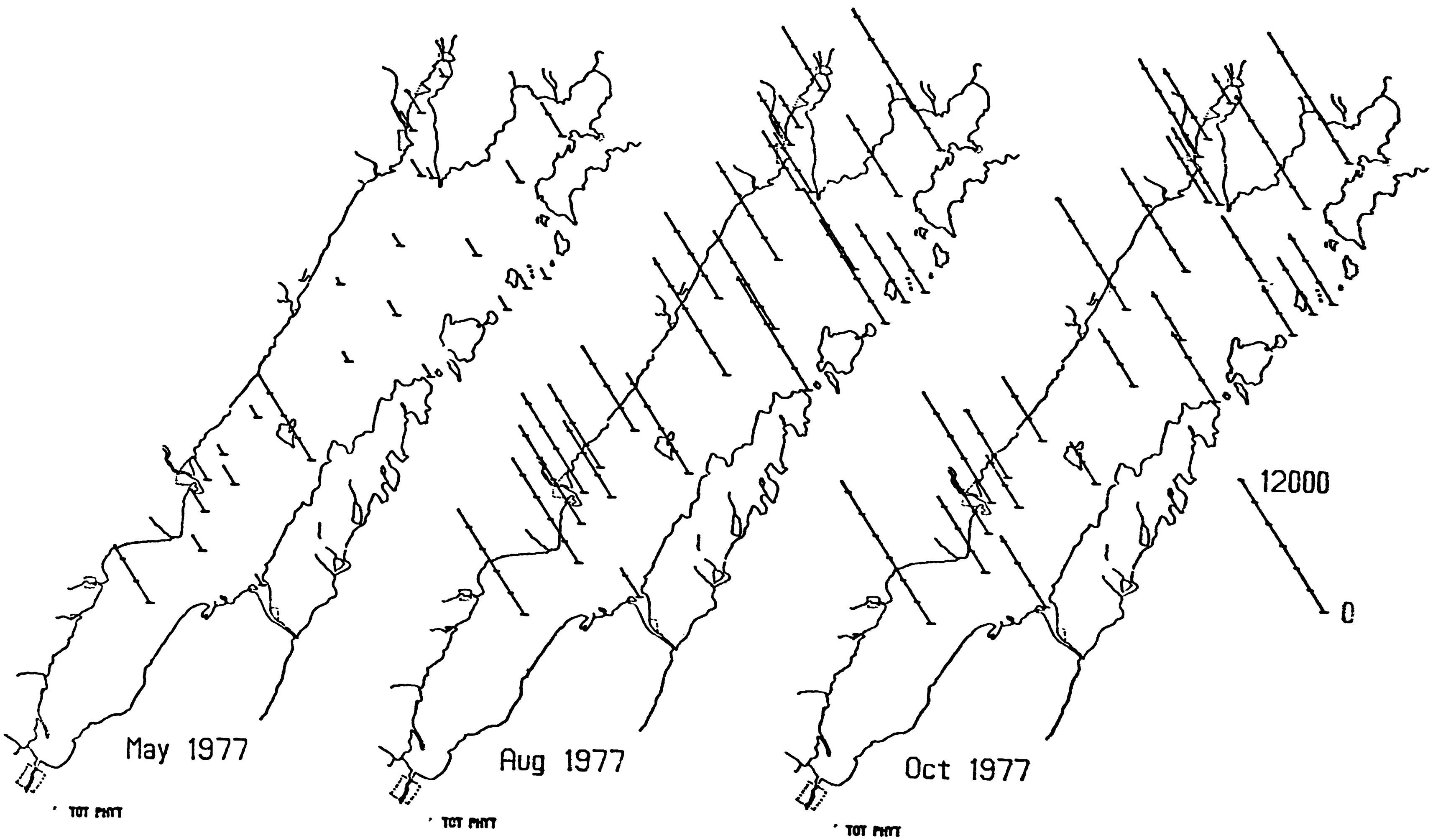

FIG. 2. Surface phytoplankton community densities.

measure of community stability is not necessarily valid (Hendrickson and Ehrlich, 1971). Species diversity indices are a function of the number of species and their proportional abundances in an assemblage. These measures are based on the assumptions that all pairs of species are equally different ecologically, and that the individuals of a species have the same physiological and ecological weight. The first assumption can be criticized, as Pielou (1974) suggests, because not all species niche hypervolumes are equal. All species are not of equal taxonomic rank, they exhibit various degrees of morphological variation. Conceptually this can be related to niche hypervolume. The niche of a species could be large because all individuals of the species have the same broad tolerance of environmental conditions. The niche could also be large because it is actually the union of the subniches of subpopulations of a species, as Stoermer and Yang (1969) have suggested of the eurytopic Fragilaria crotonensis and Asterionella formosa. In addition to the species equality complication, if relative abundances are included in the index, the ranks of physiological potential of the individuals of different species should be equal. These generalities may average out when analyzing phytoplankton communities with their large number of species. However, species diversity must be studied more thoroughly before its relationship to community structure and stability is fully realized.

May diatom diversity (S/N) averaged 0.100 and ranged from 0.018 in Sturgeon Bay to 0.301 at location 5 at Little Bay de Noc and 0.319 at location 11 near the Menominee River (Appendix C). Diversity in most of the bay was about 0.05, however, isolated groups of stations around the Menominee River and in Little Bay de Noc were substantially higher.

August surface phytoplankton diversity averaged 2.4, ranging from 1.9 to

3.0. Surface diversity was lowest north of Chambers Island. Higher values were found in the Big Bay de Noc, Little Bay de Noc and southern Green Bay. Bottom phytoplankton diversity averaged 2.7 and ranged from 1.732 to 3.334. No areal pattern of bottom diversity was recognized.

October surface diversity also generally decreased from south to north and was lowest near the Lake Michigan boundary. Diversity averaged 2.4 and ranged from 1.5 to 3.4. Higher values were noted in the October bottom communities, which averaged 2.6 and ranged from 1.2 to 3.4. Again diversity was highest overall in south-central Green Bay, decreasing in the northern bay region.

Distribution of Algal Divisions--

Blue-green algal densities (Fig. 3) were very low in May, averaging less than 100 cells/ml. Cyanophyte densities increased to an average of 3771 cells/ml in August, and were highest in the northern bay region at locations 6, 7, 9, 19, and 20. In October blue-green densities averaged about the same as August, 4060 cells/ml, but the areal distribution shifted to lowest densities in the north-central bay and high densities in the nearshore areas. Blue-green algae numerically comprised about 50% of the Green Bay assemblage in August and October (Fig. 4). Their numerical percent of the community was reduced in May to about 3%. Anacystis incerta was the predominate Cyanophyte in August and October.

May green algae densities (Fig. 5) averaged 234 cells/ml and these populations were distinctly more abundant south of Chambers Island. Chlorophyte abundance increased in August to an average of 1188 cells/ml with a relatively uniform distribution throughout the main bay. The October average dropped to 753 cells/ml with higher densities evident south of Chambers Island, nearshore at Location 8, and in Big and Little Bays de Noc. Green algae

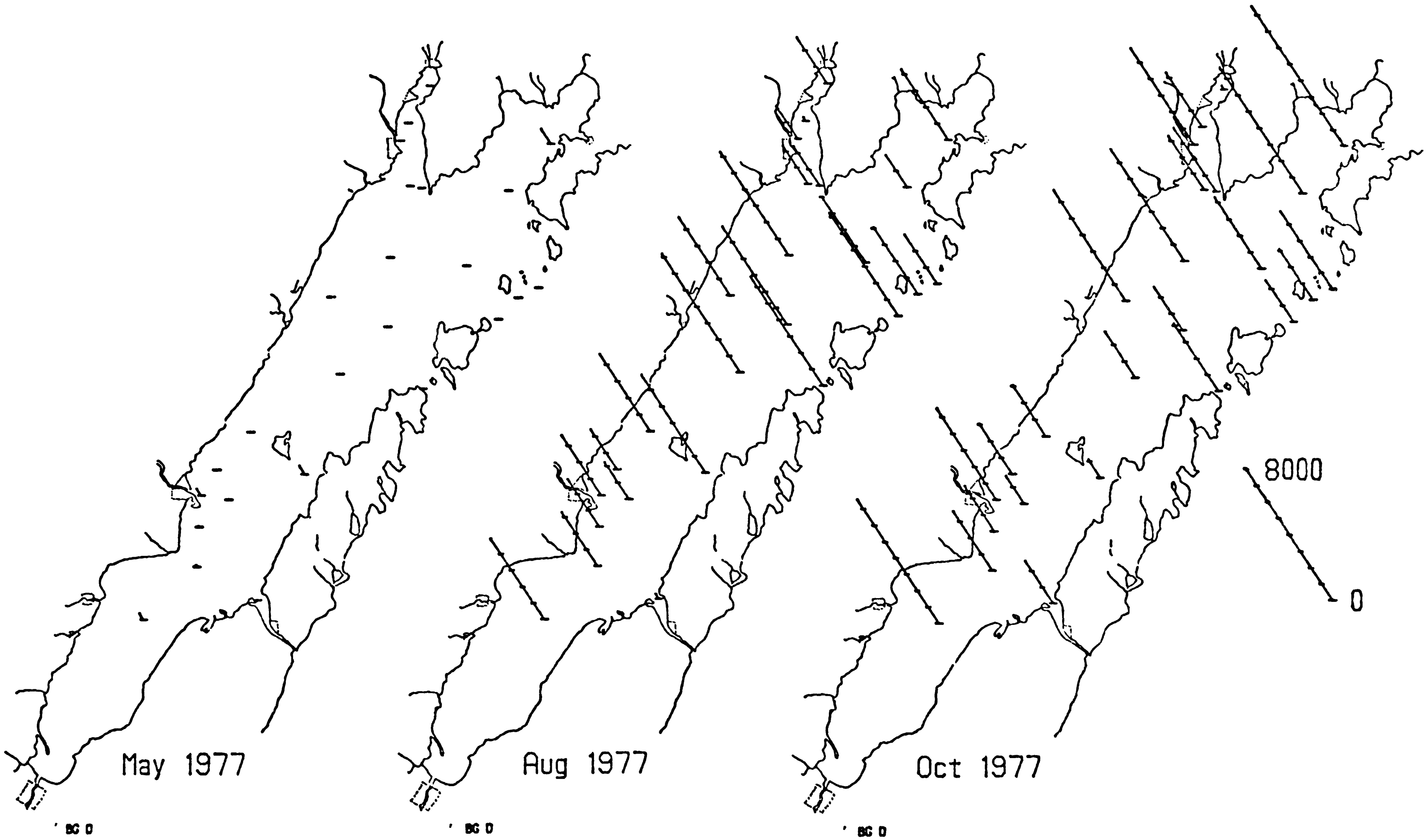

FIG. 3. Population densities of blue-green algae.

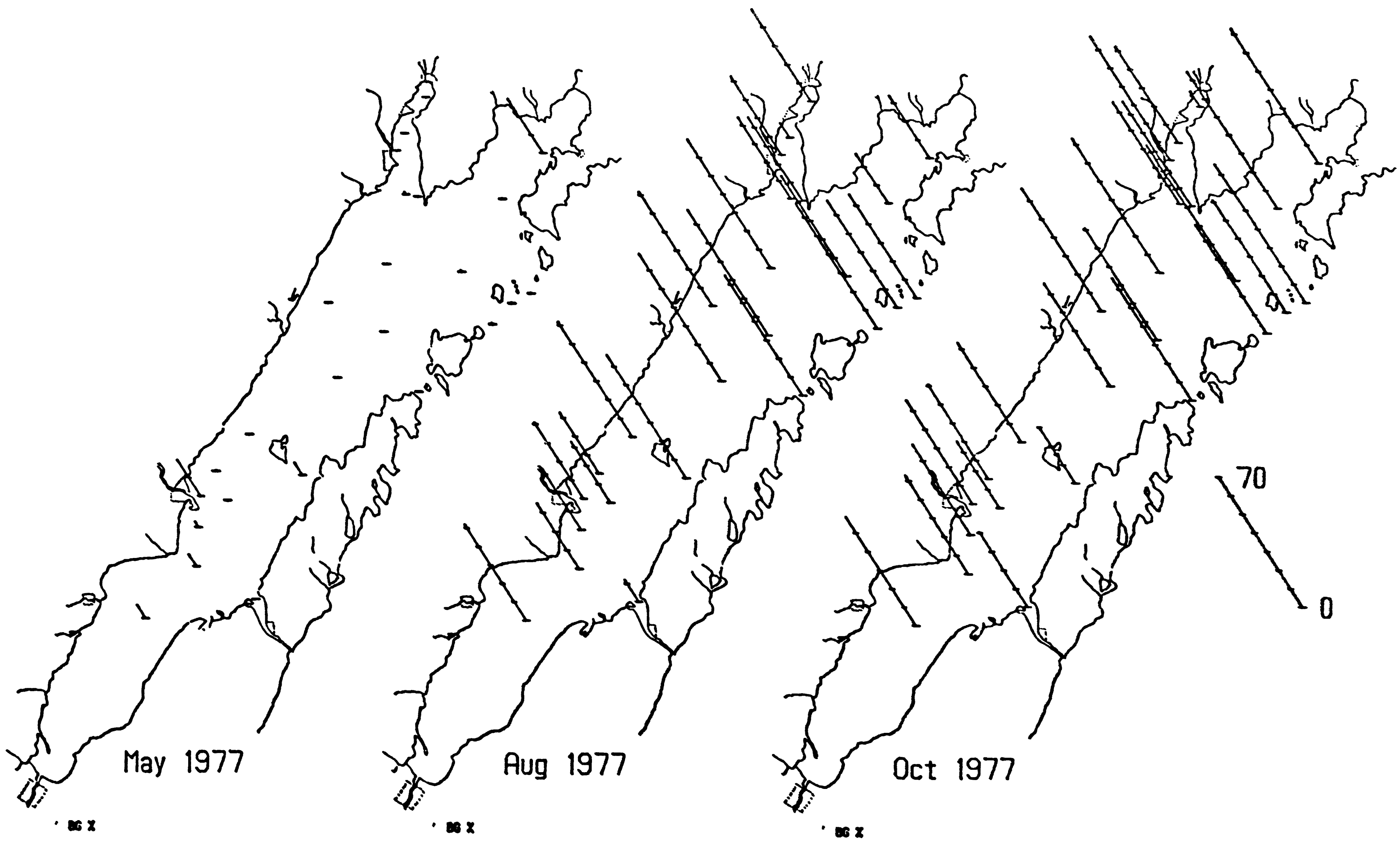

FIG. 4. Proportional abundance of blue-green algae.

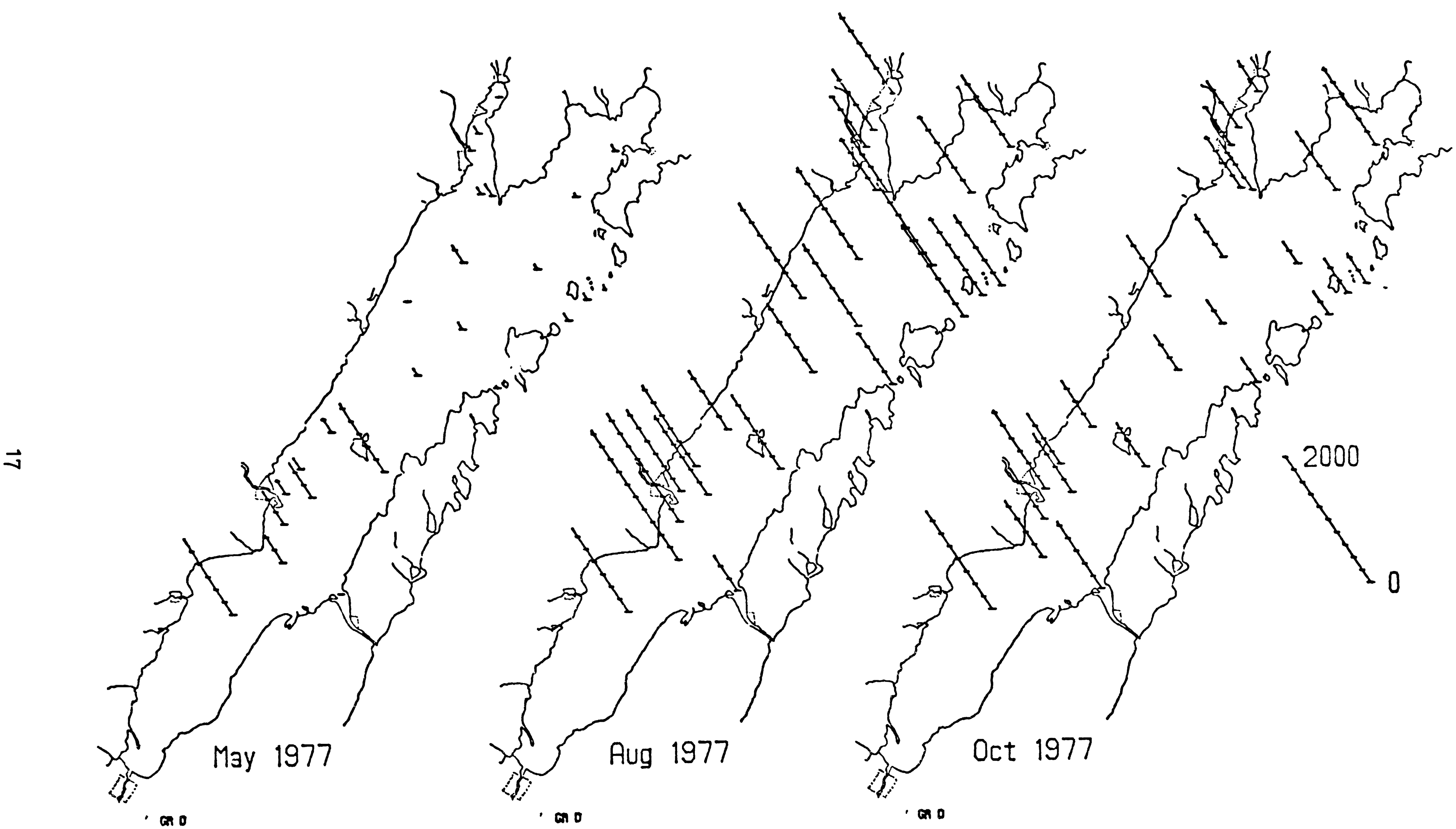

FIG. 5. Population densities of green algae.

constituted a relatively consistent fraction of the community during all sampling periods, 11-15% (Fig. 6). Reduced percentages were common at the north-central bay locations. Gloeocystis planctonica and Oocystis spp. were the most abundant taxa in both August and October.

May diatom densities (Fig. 7) averaged 391 cells/ml with no apparent differential distribution. A diatom bloom in Big Bay de Noc (2507 and 5582 cells/ml) and elevated densities around the Menominee River mouth (over 1000 cells/ml) characterized the August areal distribution. October diatom densities increased from the August average of 891 to 1458 cells/ml. October abundances were greatest, averaging over 2000 south of Chambers Island, nearshore at location 8, and in the Bay de Noc region. In August and October densities were depressed in the north-central Green Bay region. Diatoms were the most dominant division during May in Green Bay, averaging 30% (Fig. 8). Reduced percent compositions were especially apparent at most locations south of Chambers Island in May (poor sample quality of the Sturgeon Bay and northwest nearshore collections dictated counting only diatoms), and in the north-central bay area during August and October. August and October proportions, 12 and 16%, were much lower than May. Cyclotella comensis, Asterionella formosa, Fragilaria capucina, and Fragilaria crotonensis were the most common species noted in this study.

Chrysophyte densities averaged 153 cells/ml in May (Fig. 9). In August golden brown algal densities averaged 493 cells/ml with the greatest concentrations south of Chambers Island. Dinobryon divergens was abundant. October densities decreased to 138 cells/ml and Chrysosphaerella longispina was common. Ochromonas spp. was numerically dominant in August and October. Chrysophytes were proportionally more abundant, 7%, in May (Fig. 10), and in

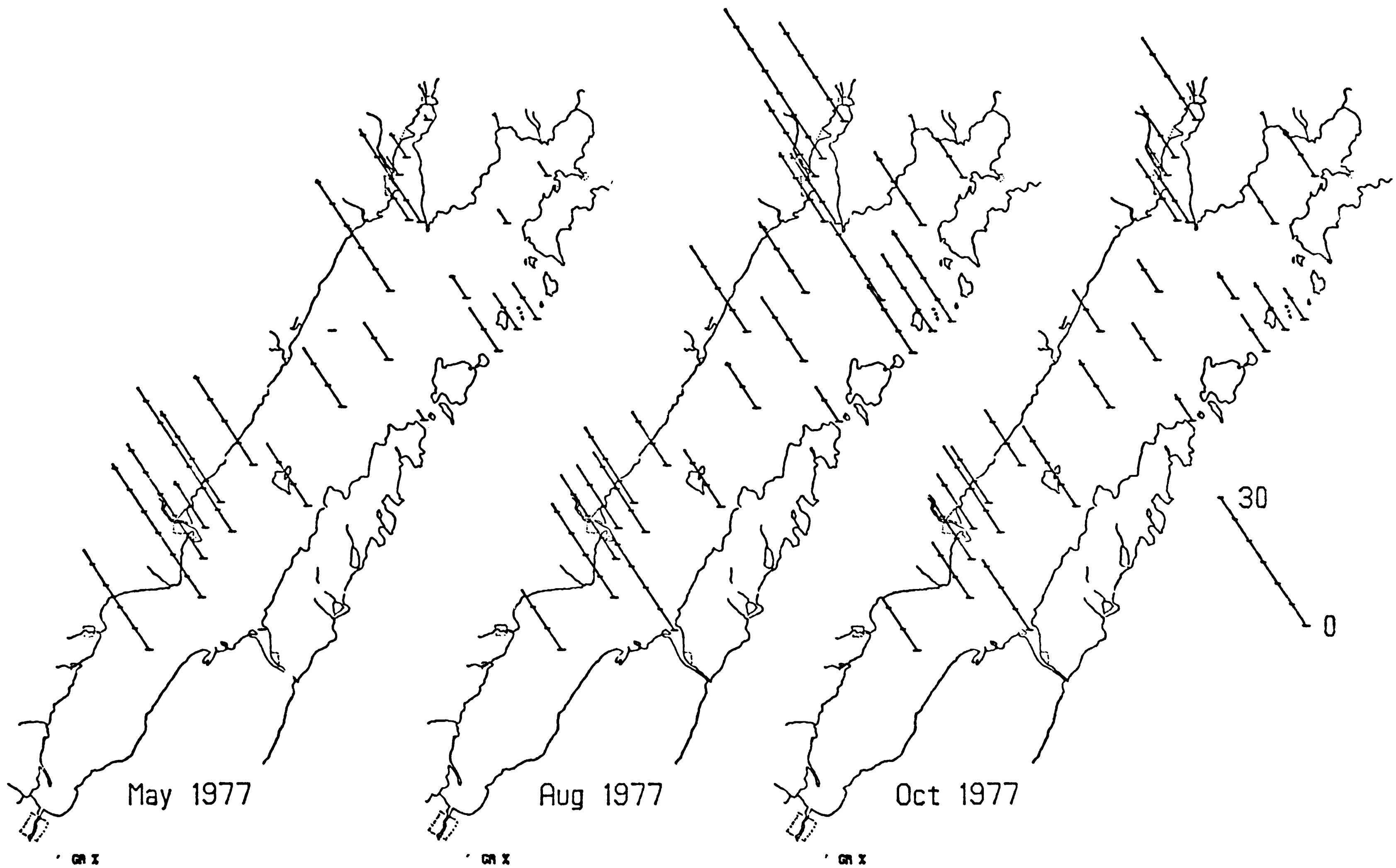

FIG. 6. Proportional abundance of green algae.

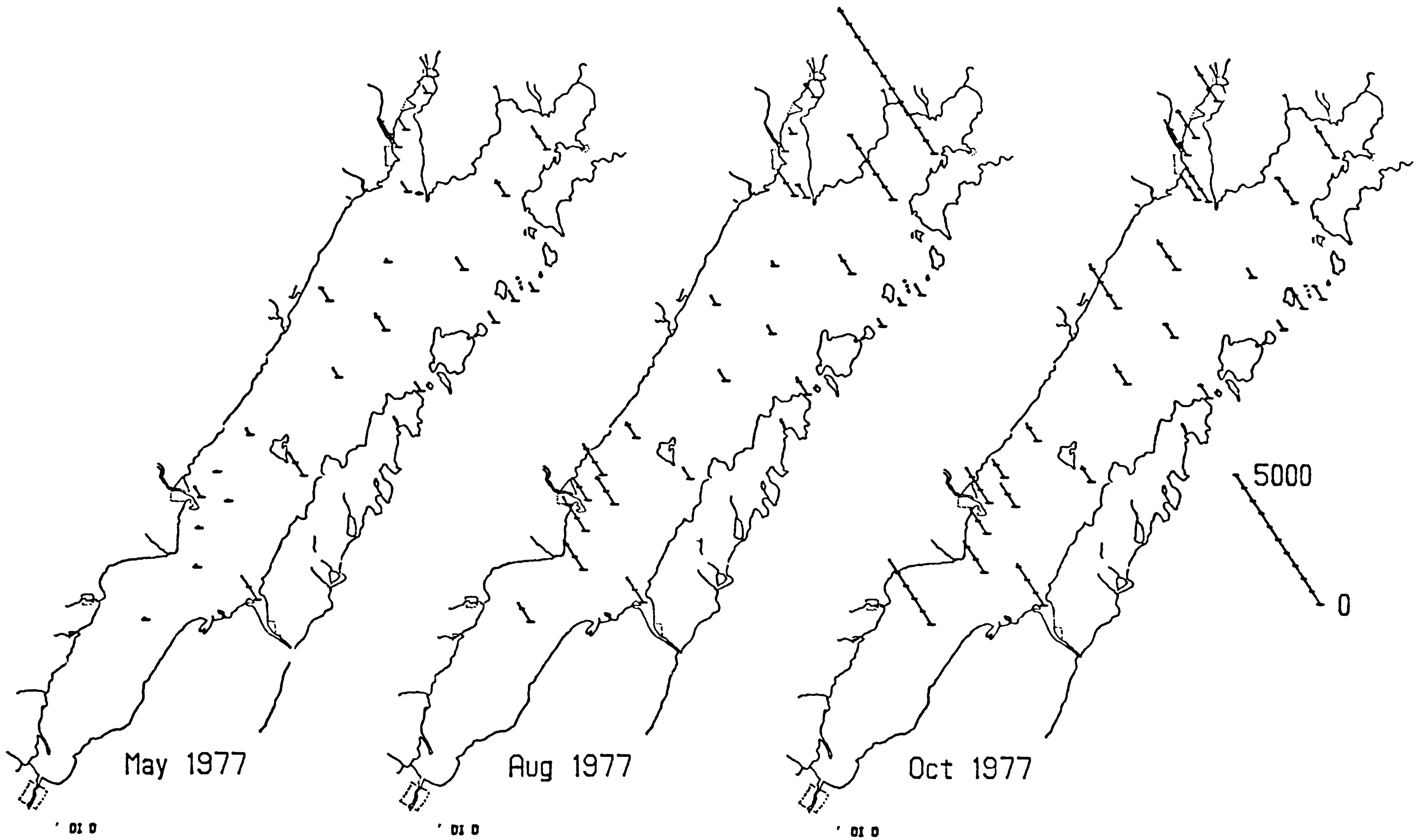

FIG. 7. Population densities of diatoms.

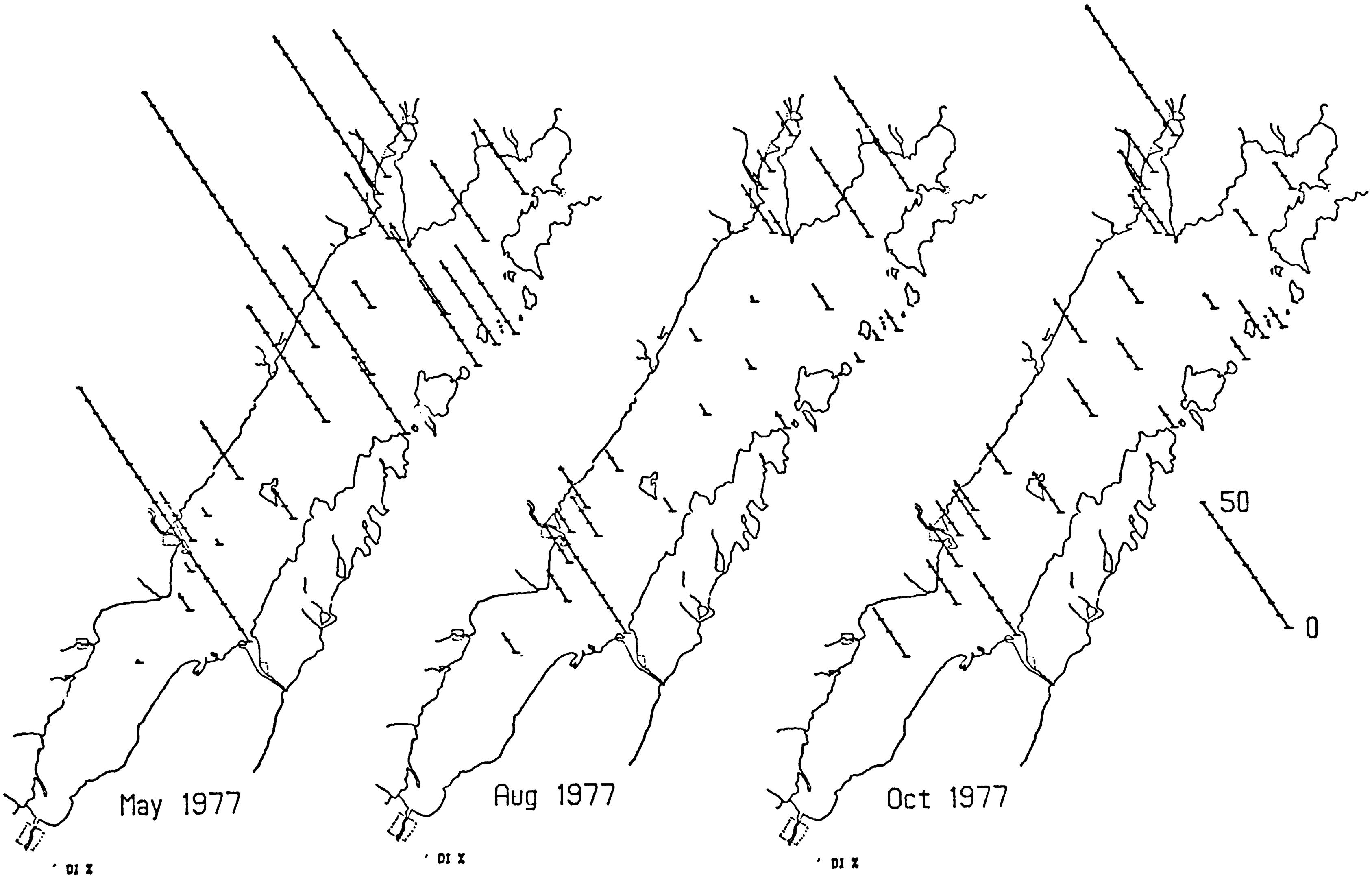

FIG. 8. Proportional abundance of diatoms.

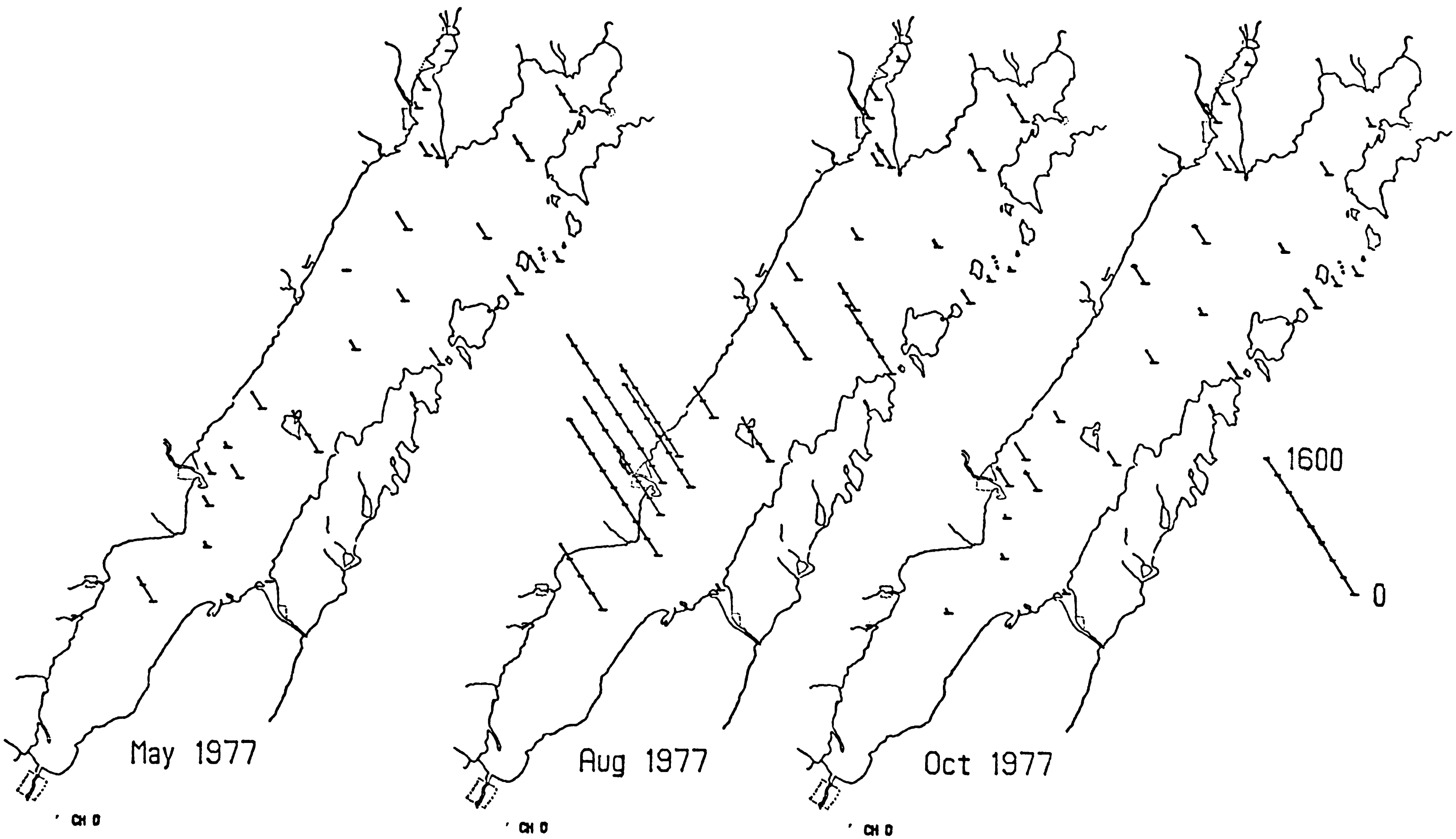

FIG. 9. Population densities of golden brown algae.

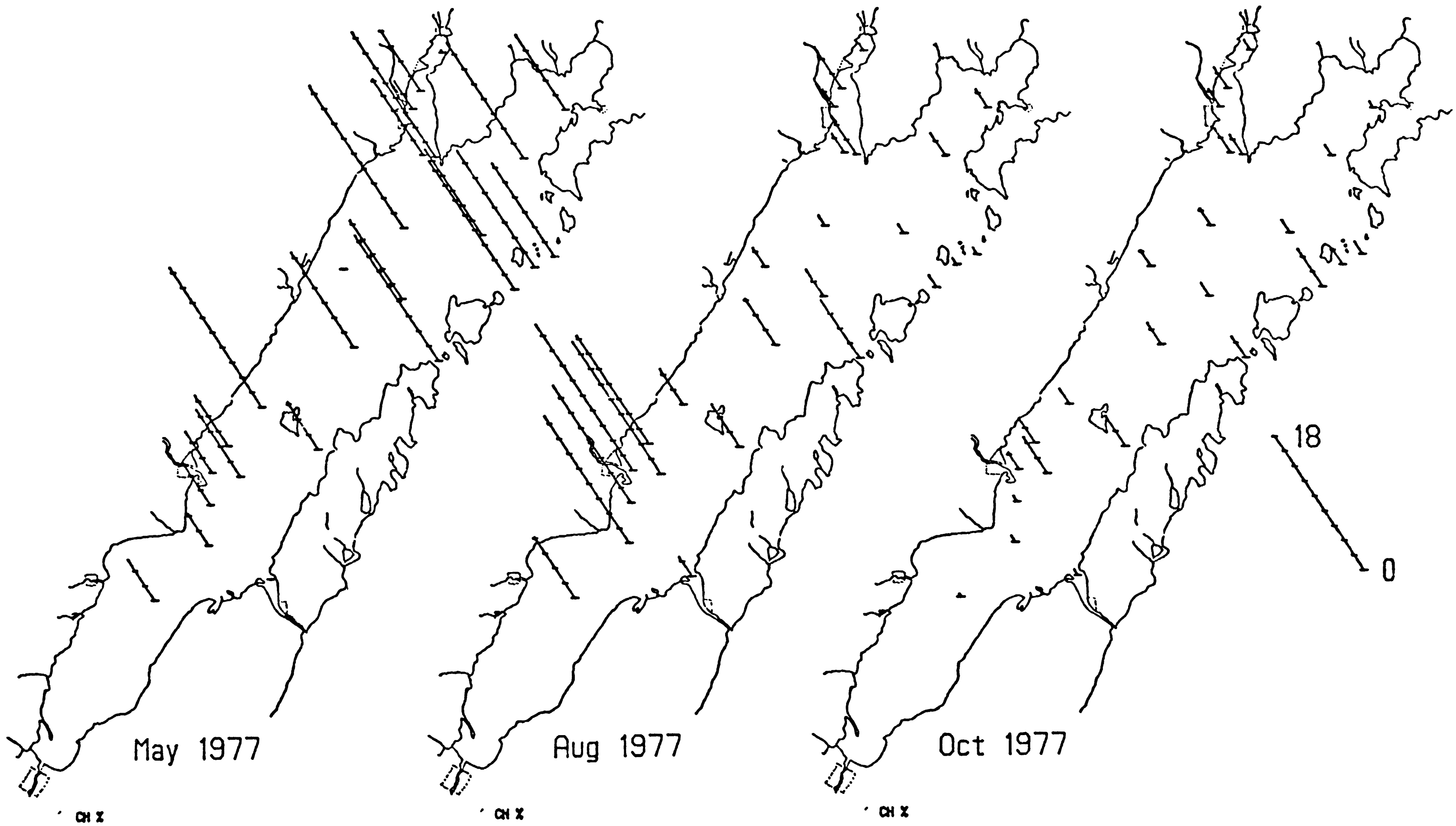

FIG. 10. Proportional abundance of golden brown algae.

August sustained that percentage only at locations south of Chambers Island. Their relative occurrence was low, about 2%, throughout the rest of the bay in August and throughout the bay in October.

Cryptophycean densities (Fig. 11) were unusually high at locations 16 and 18 in May, with densities greater than 2500 cells/ml compared to a seasonal average of 153 cells/ml. August and October densities averaged 527 and 656 cells/ml, respectively, with noticeably higher densities south of Chambers Island. Cryptophytes were apparently best represented in the May assemblages, especially south of Chambers Island and in Little Bay de Noc averaging 26% (Fig. 12). Their proportions were reduced in August and October to about 10%, but were noticeably larger in the same areas of the bay as in May. *Rhodomonas minuta* averaged as the most abundant member of this division.

Dinoflagellates and haptophytes were relatively minor components of the phytoplankton. Dinoflagellate densities (Fig. 13) were highest in nearshore areas. Pyrrophycean densities averaged less than 15 cells/ml throughout the year. Haptophyte densities (Fig. 14) were very variable, ranging from average densities of 4, 100, and 24 cells/ml on the three sampling dates to over 400 cells/ml at locations 2, 24, and 25 in Little and Big Bays de Noc in August and location 16 in southern Green Bay in October. Dinoflagellates were proportionally best represented in May as 1% (Fig. 15), especially in the northern areas of the bay.

Community Similarity--

Euclidean distances were calculated between all surface phytoplankton communities designating the variables as 25 taxa that were generally the most abundant during August and October. The general formula (Sneath and Sokal, 1973) is:

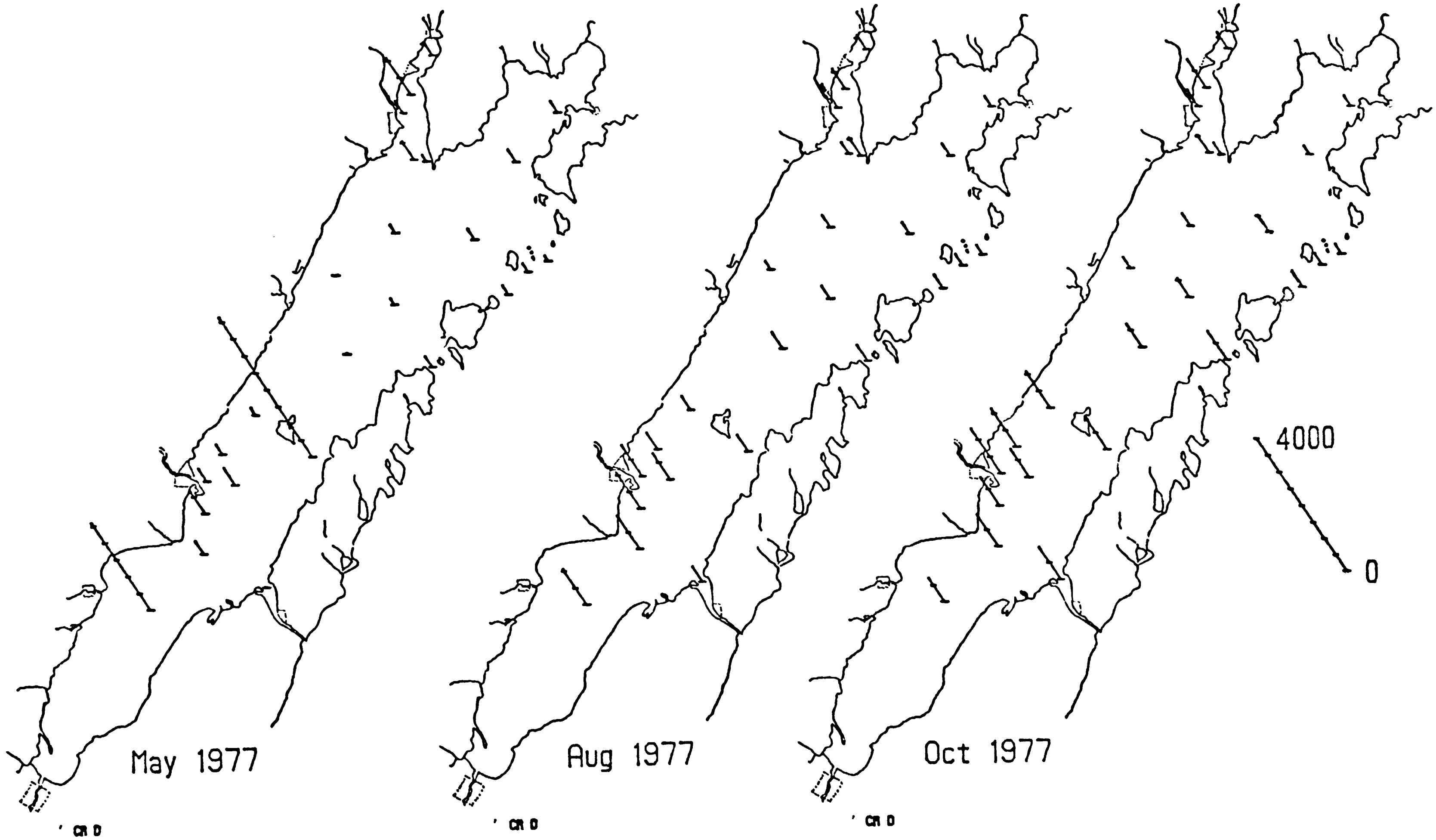

FIG. 11. Population densities of cryptomonads.

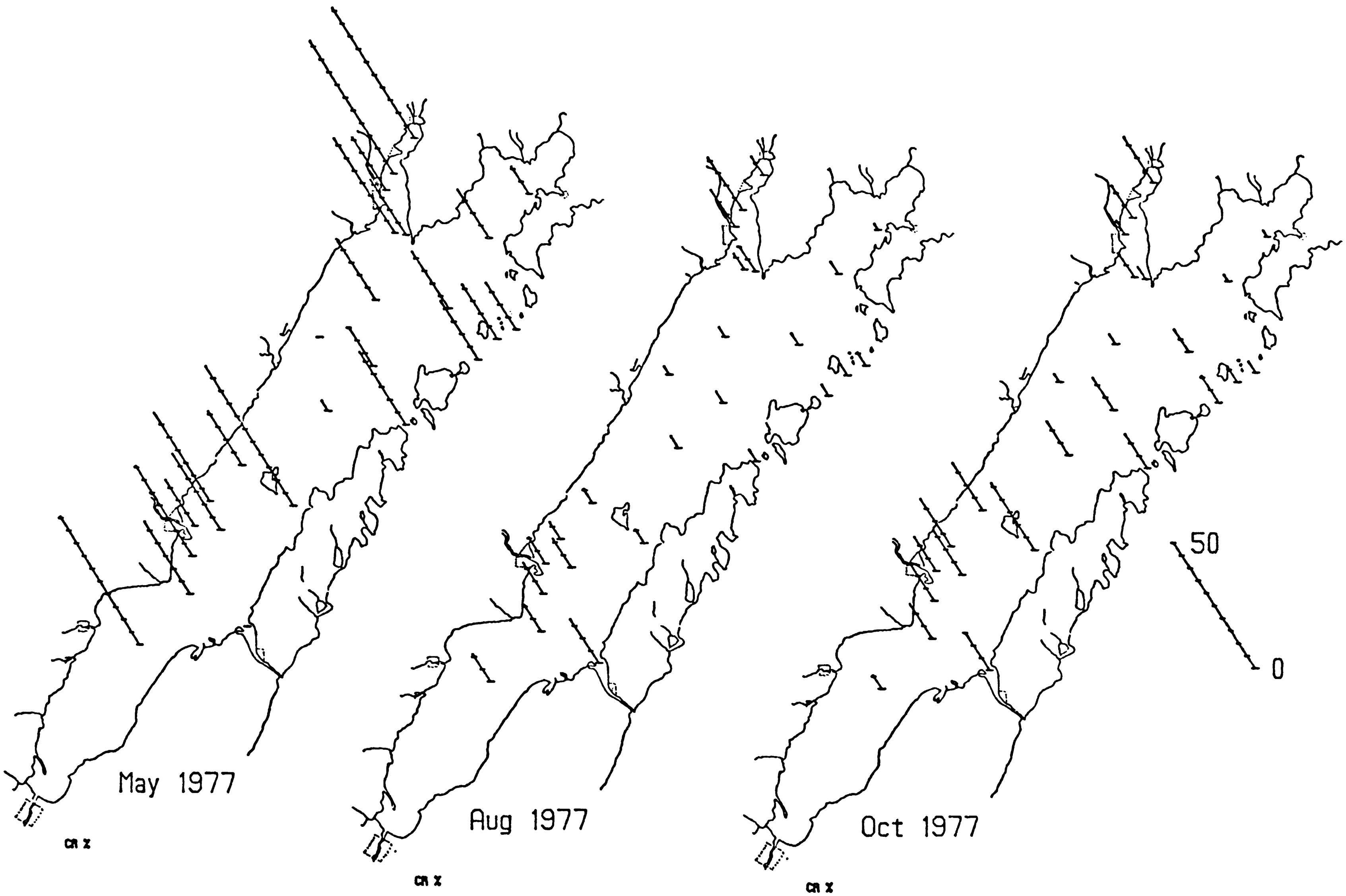

FIG. 12. Proportional abundance of cryptomonads.

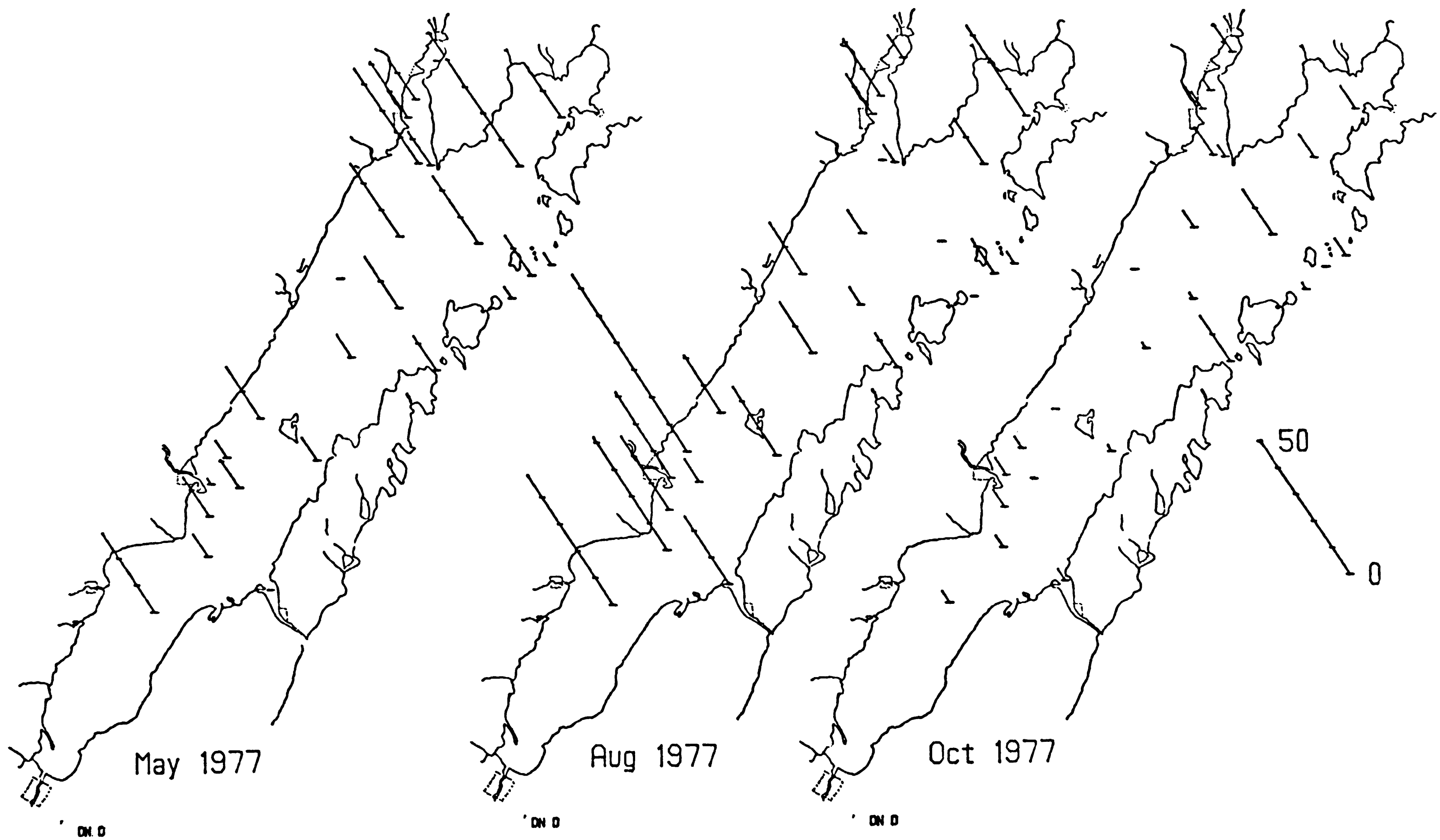

FIG. 13. Population densities of dinoflagellates.

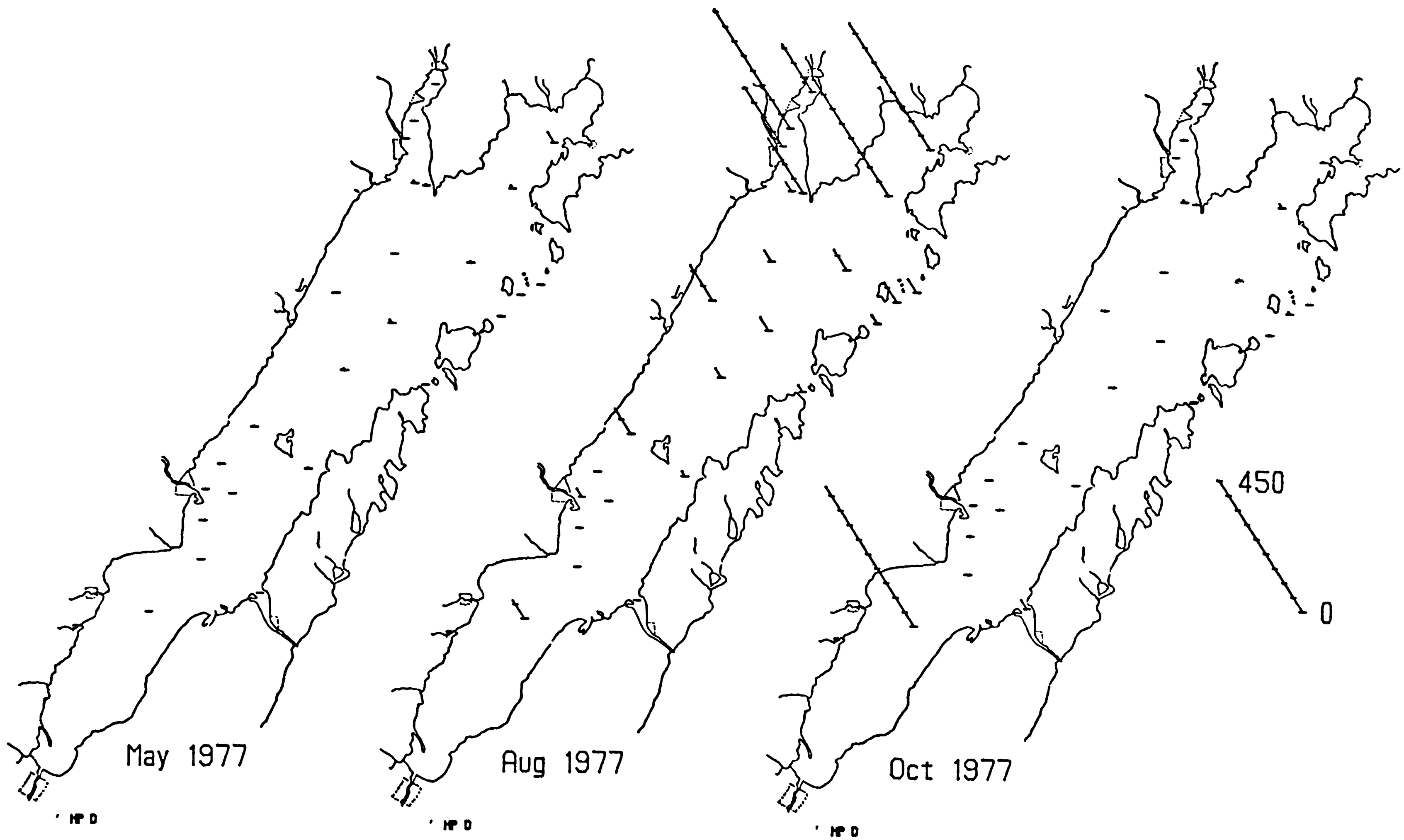

FIG. 14. Population densities of haptophytes.

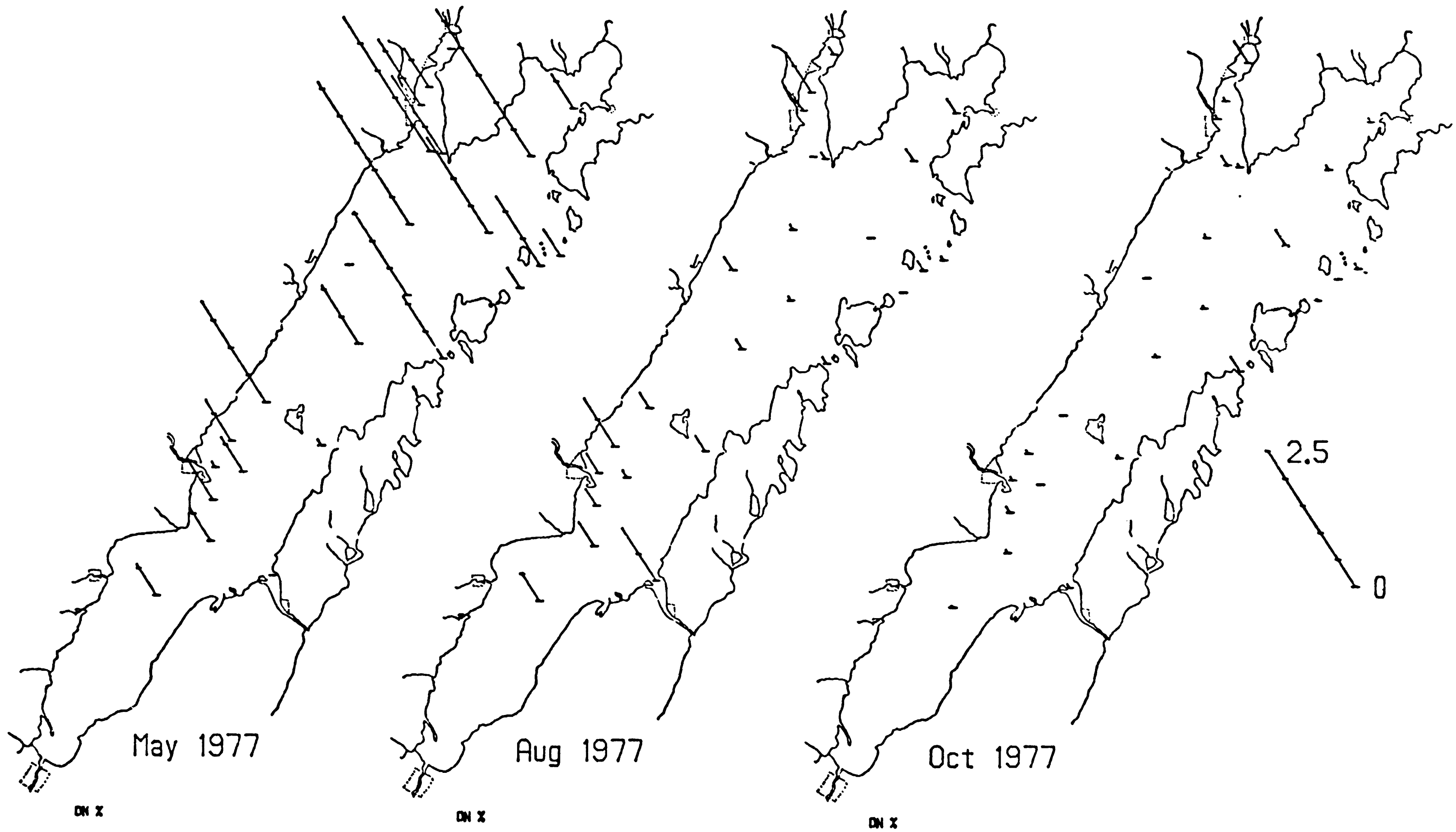

FIG. 15. Proportional abundance of dinoflagellates.

$$D = \sqrt{\sum_{i=1}^{S} (X_{ij} - X_{ik})^2}$$

where X is the density of the i^{th} taxa at the j^{th} and k^{th} locations, and S is the total number of species used as variables. Cluster analysis was then used to group similar assemblages. A minimum variance algorithm was used for clustering. This algorithm split the locations into successively smaller groups by minimizing the variance or distance within the groups. Note that distance is inversely proportional to the similarity value squared. The half matrix of euclidean distances and the cluster diagrams are in Appendix D.

May communities were not analyzed because poor sample preservation rendered taxonomic identification questionable. August surface phytoplankton communities clustered into three main regional groups (Fig. 16), Green Bay south of Chambers Island, the northern bay, and Little Bay de Noc. The region south of Chambers Island has fairly large distances between the locations within the cluster. The smallest distance associates location 16 in the extreme south and location 12 by the Menominee River mouth. Sturgeon Bay is the most dissimilar assemblage. The north-basin cluster is also divided into two clusters, essentially north and south of Washington Island.

In October the phytoplankton assemblages again grouped into two main clusters, separated at Chambers Island (Fig. 16). Location 16 in southern Green Bay and location 12 near the Menominee River mouth grouped again, while the remaining stations south of Chambers Island clustered and included Sturgeon Bay, location 17, among them. The northern bay cluster north of Chambers Island was again subdivided north and south of Washington Island with another cluster

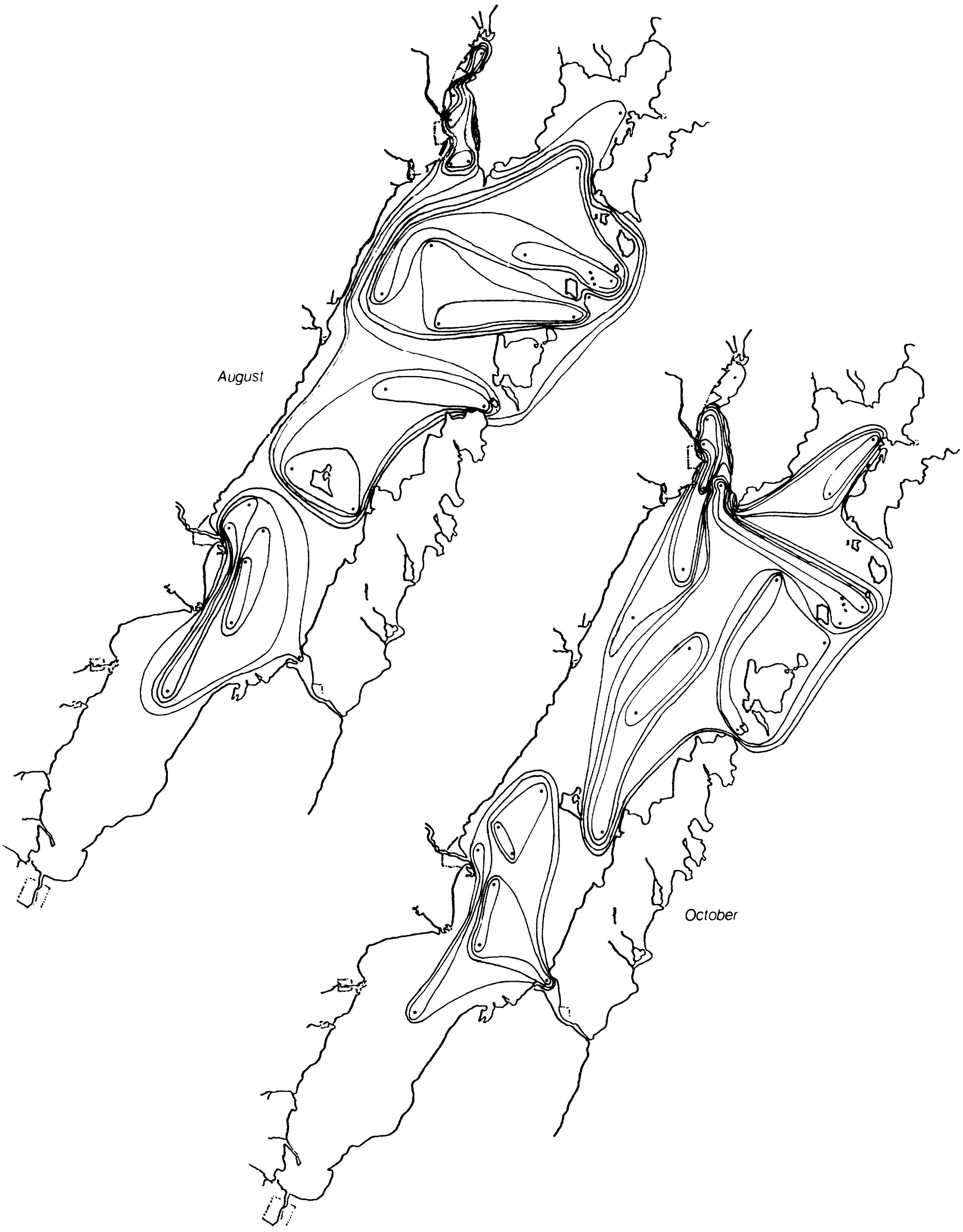

FIG. 16. Cluster association of phytoplankton communities.

surrounding Washington Island. This season both Big and Little Bays de Noc remained separated from the two main bay clusters. The Little Bay de Noc cluster also incorporates locations 6 and 8 along the northwestern nearshore area of Green Bay. It is interesting to note the similarities between locations 22, 23, and 8 in August and locations 22 and 5 in October which extend from the Lake Michigan interface to the western shore of Green Bay.

Locations 7, 16, and 17 were strategically chosen to provide phytoplankton assemblages typical of the less and more impacted areas of Green Bay and Sturgeon Bay. Contour plots were constructed utilizing the distances between a chosen location and all other sampling locations. Smaller dissimilarities in relation to location 7 (Fig. 17) were oriented in more of a northern direction in August, whereas in October dissimilarities were smallest to the south. In both cases, most of the north-central basin of the bay was included within the 1.0 contour. Location 8 is an exception in October, when it apparently has a very different community. Distances from location 16 (Fig. 18) are much greater in October than in August. Note the intruding dissimilar assemblages oriented around Sturgeon Bay in August. Utilizing Sturgeon Bay (Fig. 19) as base location, it is evident that very dissimilar phytoplankton assemblages surround it in August, but in October the surrounding locations are more similar.

Population Analysis

Anacystis incerta (Lemm.) Drouet *et* Daily--

These organisms are known to cause nuisance blooms because of their large colony size and ability to form gas vacuoles (Drouet and Dailey, 1956). Stoermer et al. (1975) observed large populations at various times in different

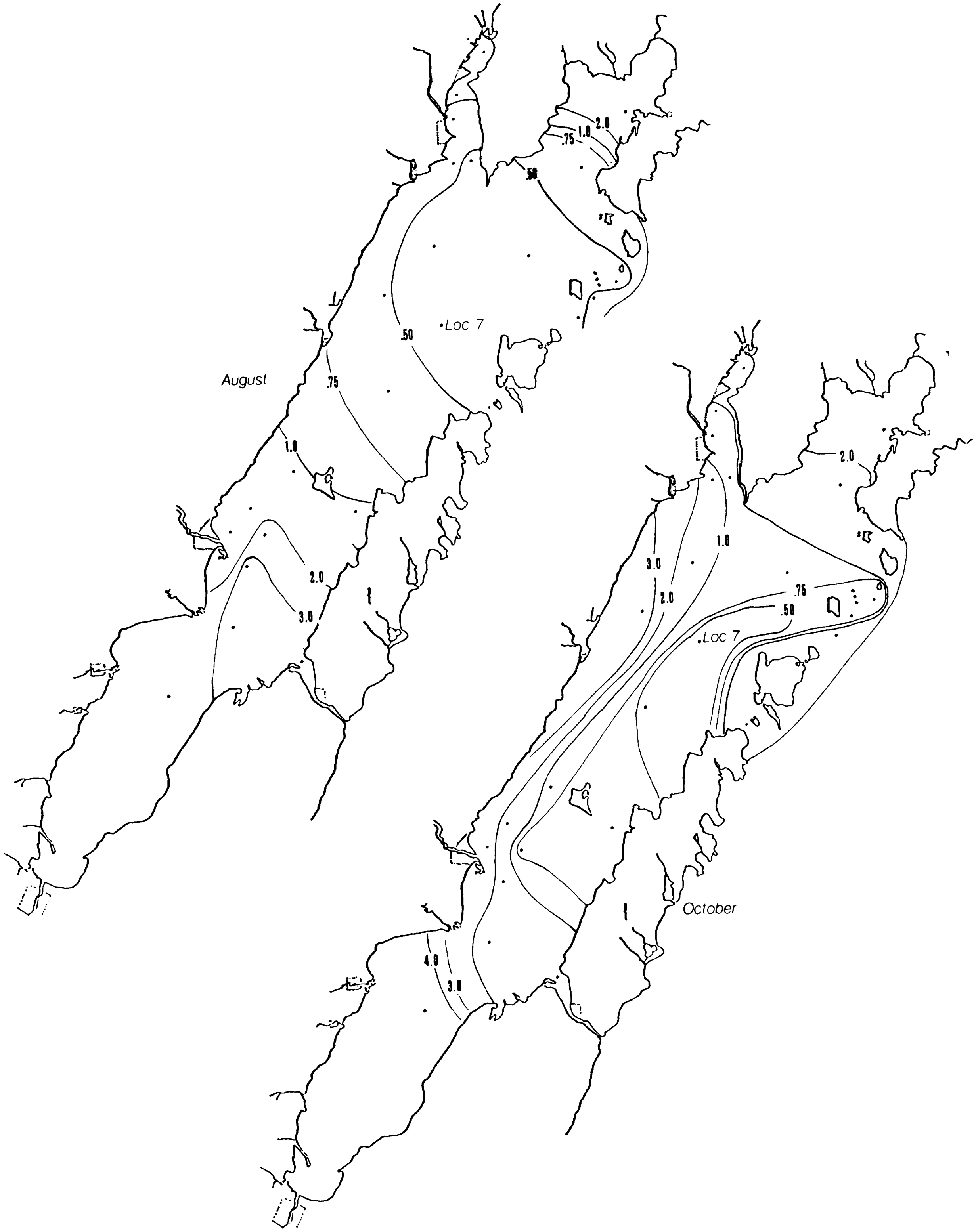

FIG. 17. Euclidian distance contours oriented around Location 7 during August and October.

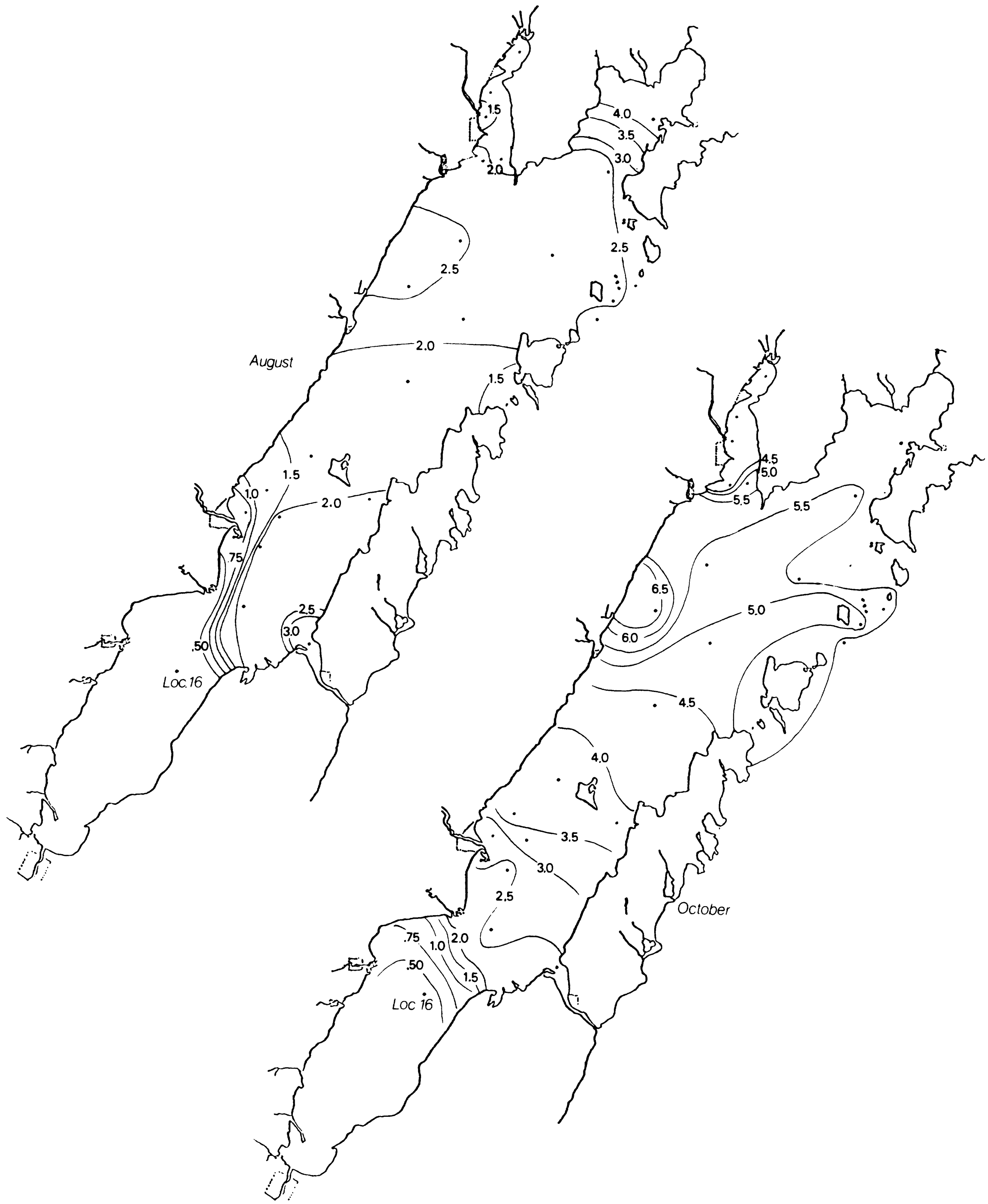

FIG. 18. Euclidian distance contours oriented around Location 16 during August and October.

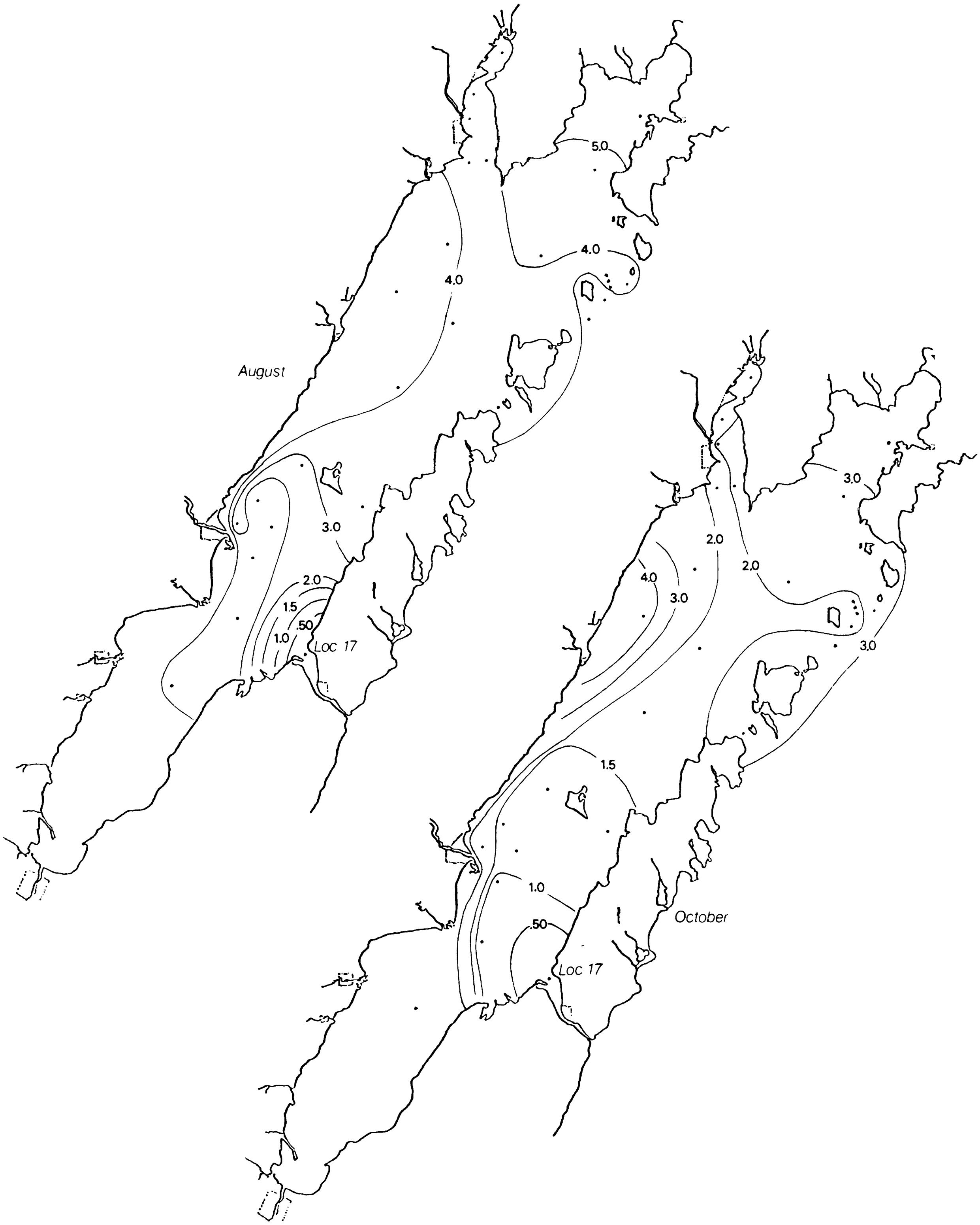

FIG. 19. Euclidian distance contours oriented around Location 17 during August and October.

locations in Lake Ontario. They suggest *A. incerta* is most common in silica depleted phytoplankton associations. In northern Lake Michigan 3000 to 6000 cells/ml were present in late August and lower densities observed in mid-September (Schelske et al., 1976).

This taxon was very abundant in August and October throughout Green Bay (Fig. 20) with population densities commonly as great as 7000 cells/ml. The irregular densities of this organism prohibit identification of any clear preferential distribution.

Gomphosphaeria lacustris Chod.--

Skuja (1956) described it as numerous but seldom dominating with a widespread distribution. It is apparently eurytopic in the Great Lakes, having been observed in Lakes Superior, Huron, and Ontario (Schelske et al. 1976; Stoermer et al., 1975). It reportedly is an abundant component of sparse silica-limited summer phytoplankton populations in the upper Great Lakes. Its distribution in Lake Huron demonstrates reduced populations in the more perturbed areas of Saginaw Bay (Stoermer and Kries, in press).

In Green Bay (Fig. 21) populations first appeared in August samples. The number of colonies/ml increased markedly in October. In August and October its distribution was relatively uniform throughout the bay.

Gloeocystis planctonica (West *et* West) Lemm.--

Skuja (1956) described this taxon as numerous at various times of the year. Great Lakes populations indicate a summer maximum (Stoermer et al., 1975; Schelske et al., 1976; Stoermer and Kreis, in press). It has been described as a characteristic component of silica limited phytoplankton

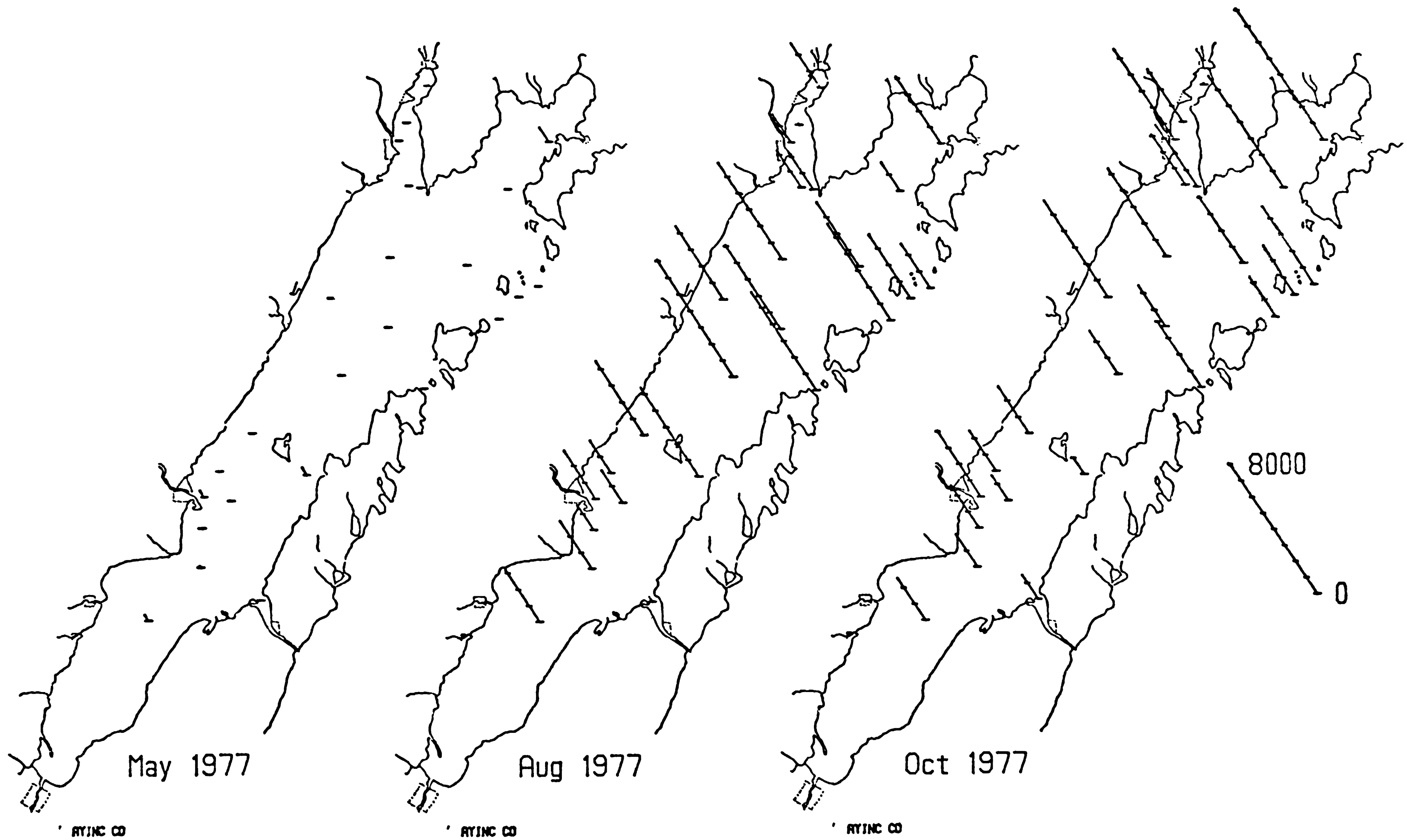

FIG. 20. Population densities of ***Anacystis incerta***.

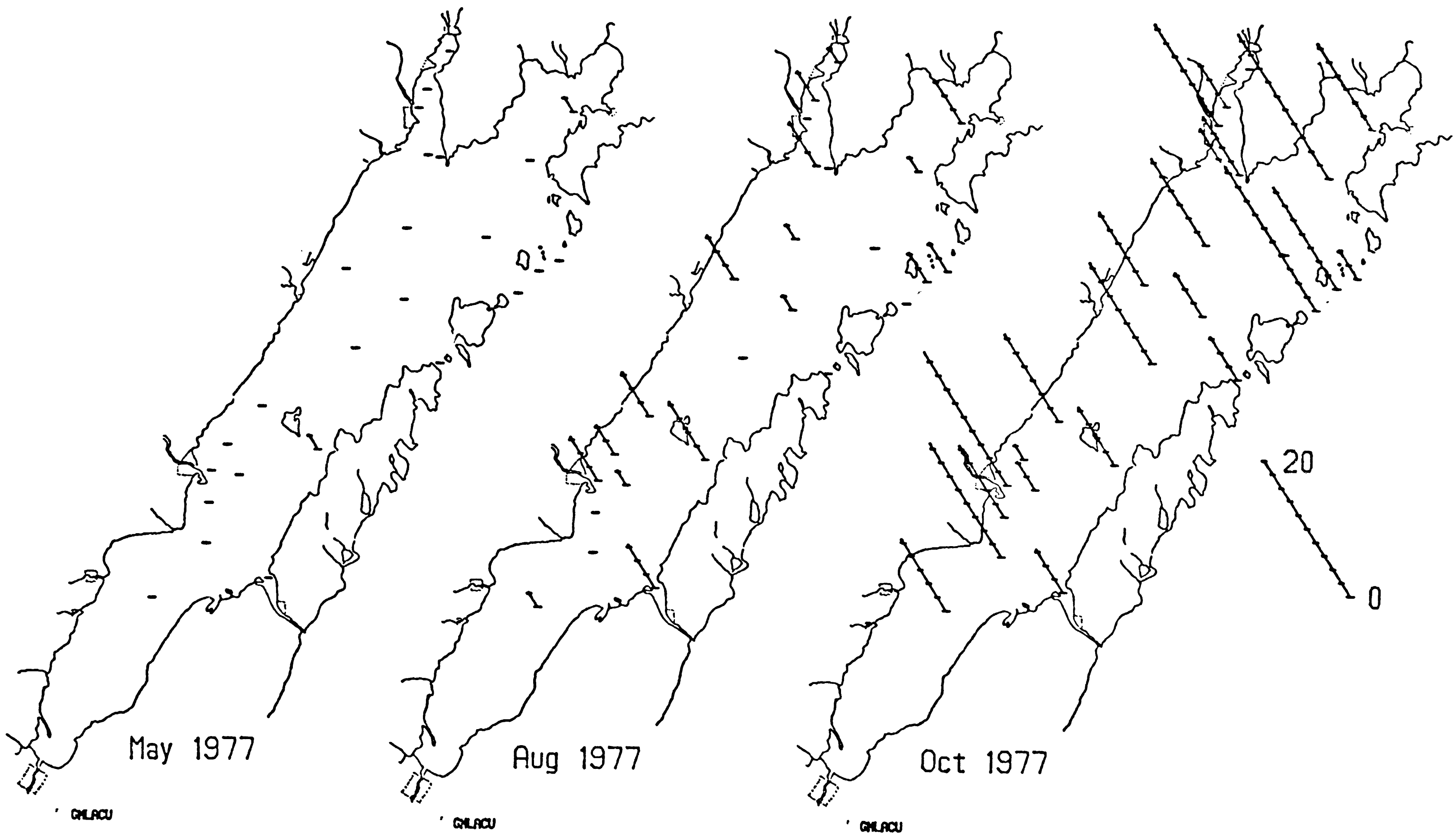

FIG. 21. Population densities of *Gomphosphaeria lacustris*.

associations in southern Lake Michigan.

In Green Bay (Fig. 22) this taxon was scarce in May, most abundant in August, and uniformly present at low densities in October. Slightly increased population densities were observed south of Chambers Island in August.

Scenedesmus denticulatus var. *linearis* Hansg.--

The taxonomic obscurity of this organism may be the reason for the limited number of reports of its occurrence in the literature. Green Bay populations (Fig. 23) were very low in May and much greater in August and October. The highest densities were recorded in August at the northwest nearshore location and in Big Bay de Noc.

Scenedesmus quadricauda (Turp.) Bréb.--

Skuja (1956) describes this as a sporadic component of larger lake phytoplankton assemblages. It has been reported from Lake Erie (Taft and Taft, 1971) and fairly abundant offshore in Lake Ontario (Stoermer et al., 1975). It does not appear in the offshore waters of the upper Great Lakes (Stoermer and Ladewski, 1976) but has been recorded as important near the mouth of the Grand River in Lake Michigan (Kopczynska, 1973). This species appears to respond postively to eutrophic habitats.

In Green Bay (Fig. 24) it was rare in May, but increasing population densities were noted in August to October. The one unusually high value in May may be a result of the unseasonally high water temperature at locations 18 and 17. Non-diatom algae were not counted at location 17, so no record is available. August and October abundances are markedly reduced in the open bay north of Chambers Island.

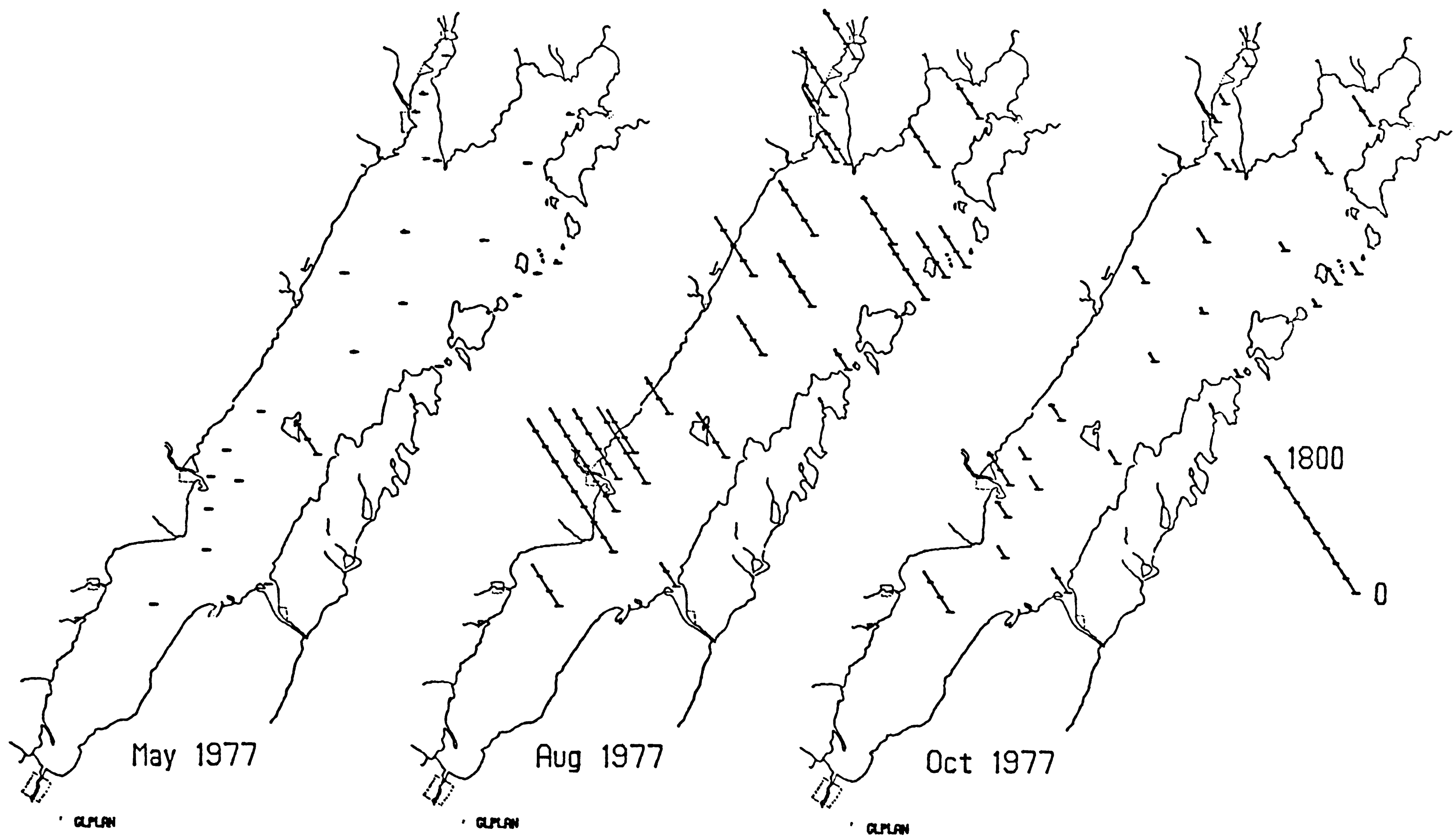

FIG. 22. Population densities of *Gloeocystis planctonica*.

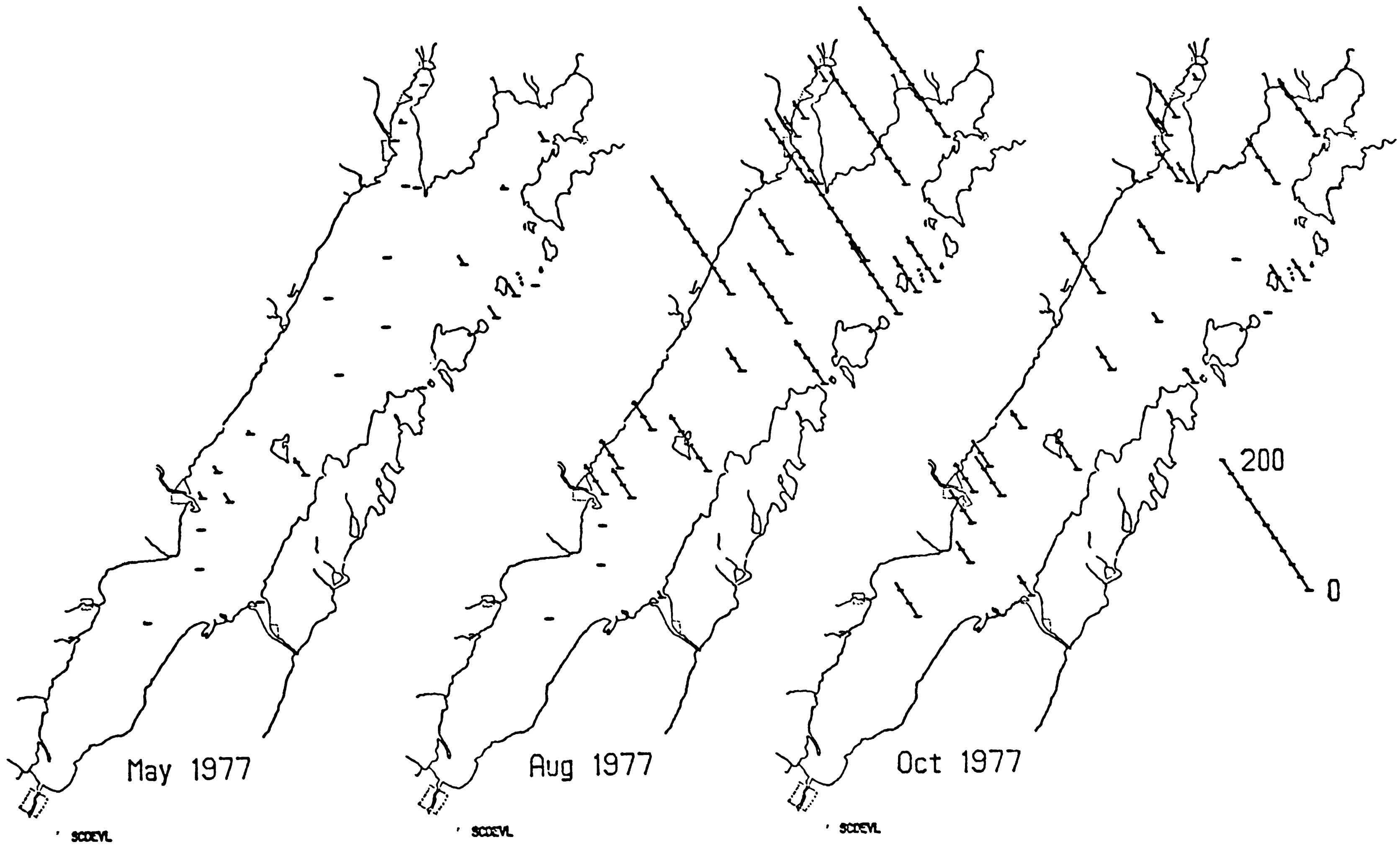

FIG. 23. Population densities of Scenedesmus denticulatus var. linearis.

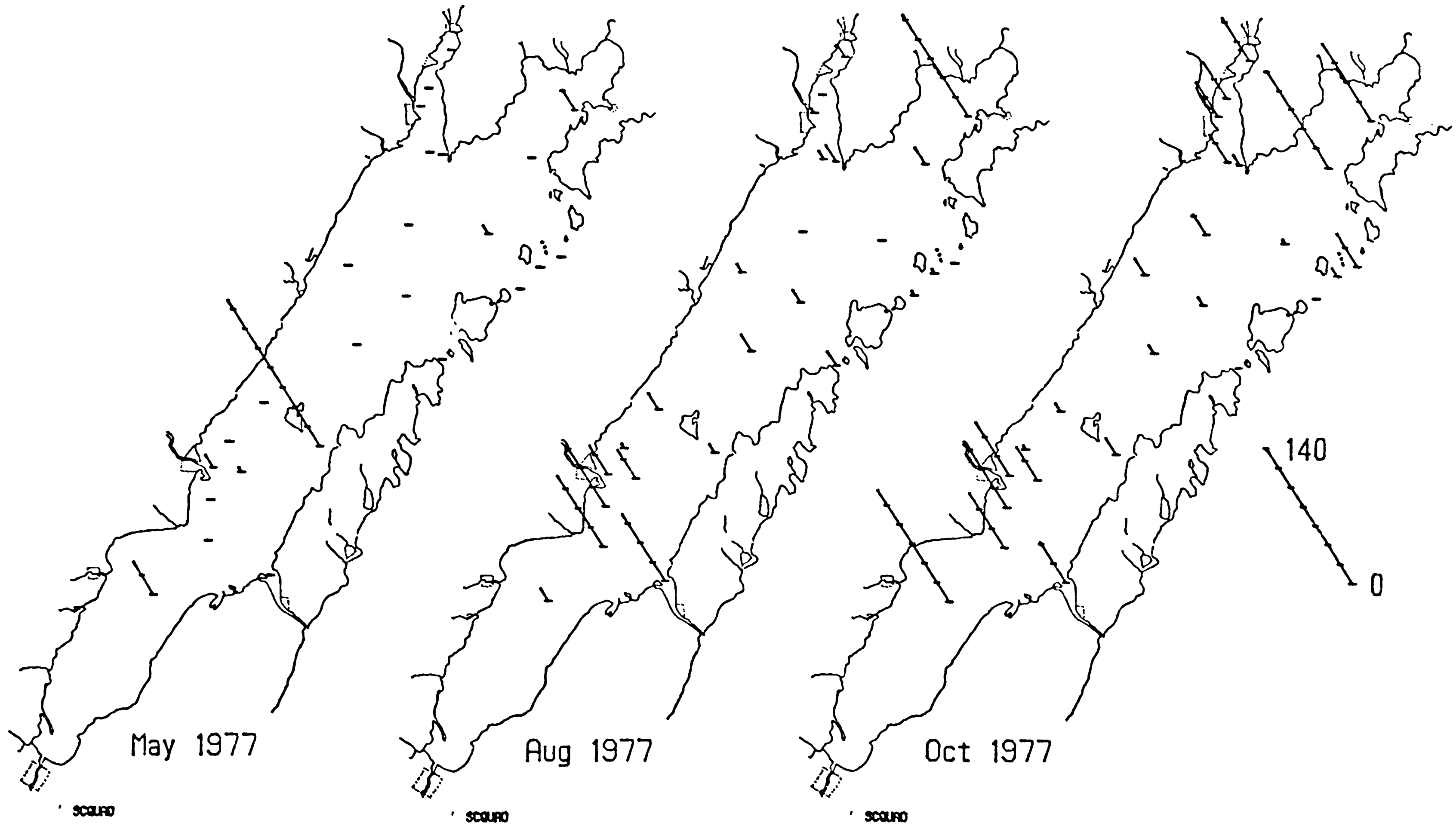

FIG. 24. Population densities of *Scenedesmus quadricauda*.

Cyclotella stelligera (Cl. *et* Grun.) V.H.--

Densities of this taxon have decreased in Lake Erie from 1938 to 1965 (Hohn, 1969). Stoermer and Ladewski (1976) assign it a double temperature optimum of 8 and 18^{o}C. It had highest population densities in September in northern Lake Huron (Schelske et al., 1976) and seems to have a fall maximum (Lowe, 1974). Cholnoky (1968) says this taxon grows in eutrophic waters, however, it was less abundant in highly eutrophic Saginaw Bay than in less eutrophic nearshore waters (Schelske et al., 1974) and was more common in offshore waters of northern Lake Huron. It was reportedly most abundant in the north and western region of Green Bay (Holland and Claflin, 1975).

In 1977 its Green Bay populations (Fig. 25) were observed sporadically in August and October and absent in May. Its largest populations were found in the northern bay region in Big Bay de Noc and along the Lake Michigan boundary.

Cyclotella comensis Grun.--

Described as euplanctonic from lakes of subalpine and alpine regions (Huber-Pestalozzi, 1942), it was formerly found in primarily oligotrophic areas. It has been reported as a minor component of plankton assemblages in Lake Superior and northern Lake Huron (Schelske et al. 1972,1974; Lowe, 1976). It was reported from nearshore areas in southern Lake Huron with an August bloom less than 2500 cells/ml (Stoermer and Kreis, in press). It was, however, absent from Saginaw Bay.

In Green Bay (Fig. 26), May populations were greater than 100 cells/ml in Big Bay de Noc and absent through most other parts of the Green Bay system. Average densities increased in August throughout the bay, especially in Big Bay

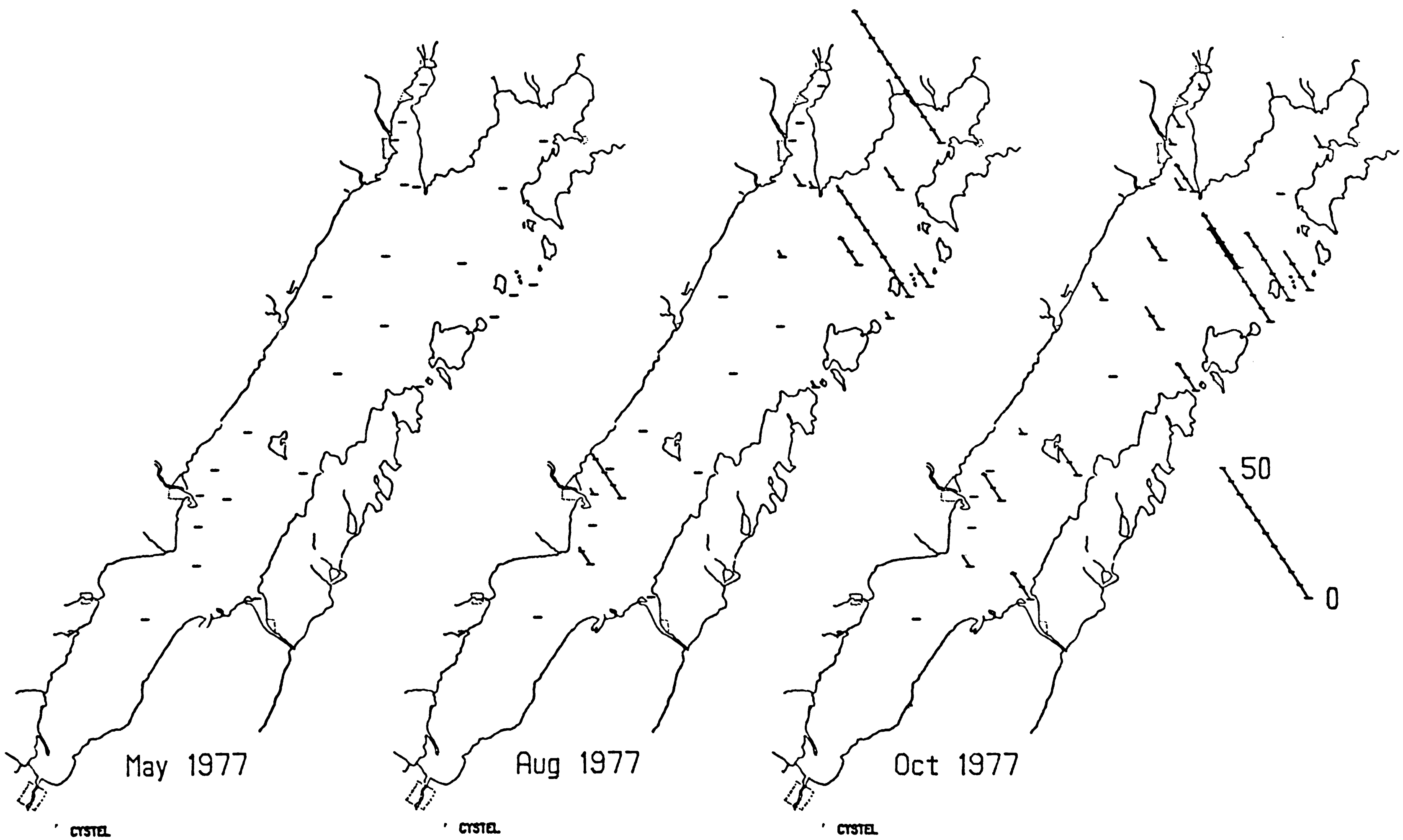

FIG. 25. Population densities of *Cyclotella stelligera*.

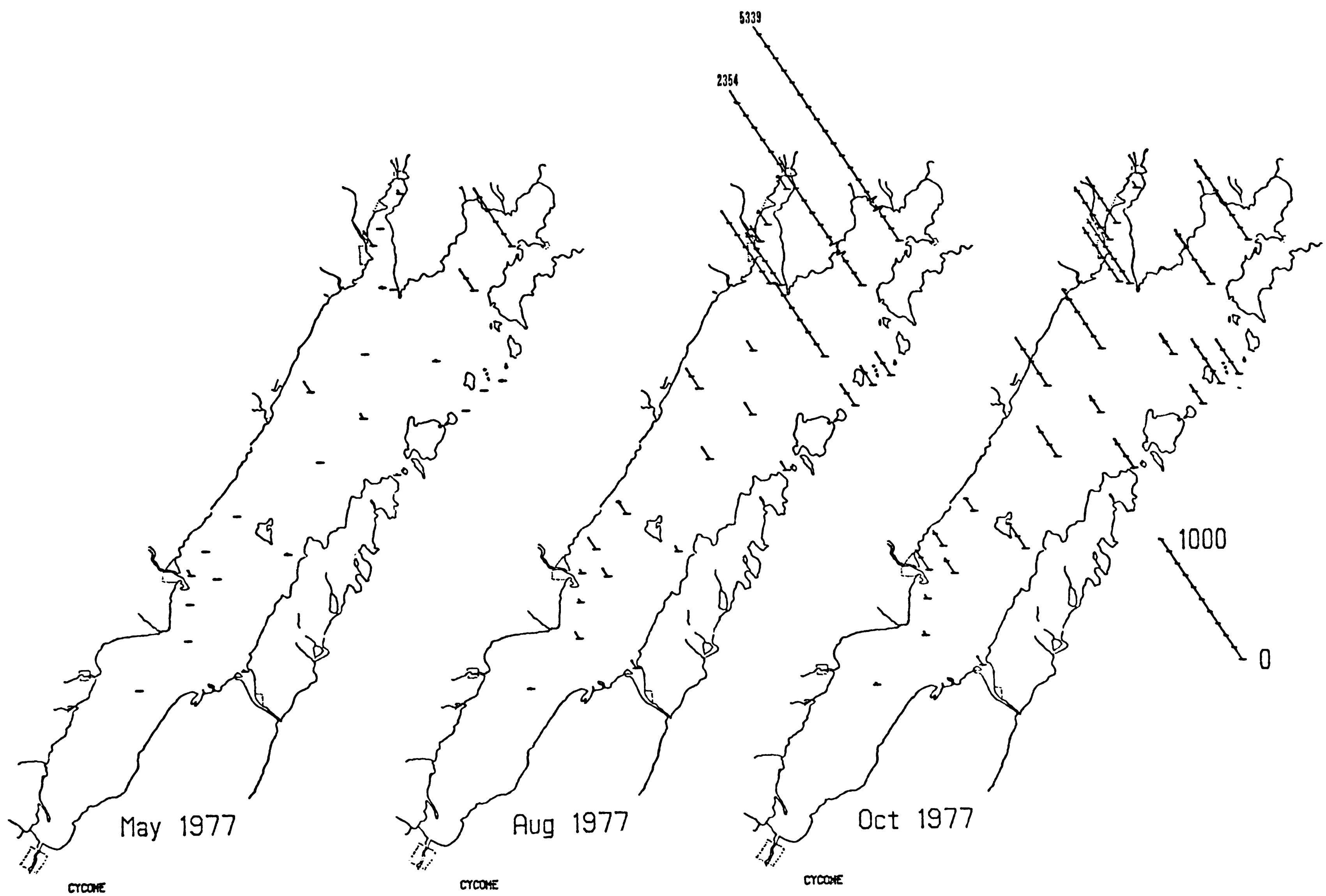

FIG. 26. Population densities of Cyclotella comensis.

de Noc where a bloom of greater than 5000 cells/ml was encountered. The Big Bay de Noc bloom subsided in October, but substantial densities remained at most locations north of Chambers Islands, especially in the Bay de Noc complex.

Cyclotella comta (Ehr.) Kütz.--

Hustedt (1957) describes the taxon as an oligohalobic, sapoxenous alkaliphil. It has been recognized to be a component of oligo-mesotrophic waters (Hutchinson, 1967; Schelske et al., 1976) which is substantiated by its absence in Lake Erie (Hohn, 1969) and its low density populations in Lake Ontario. It has been found frequently in the upper Great Lakes (Schelske et al., 1972,1974) where its range may be becoming more restricted due to increased levels of eutrophication (Stoermer and Yang, 1970). It apparently has a seasonal optimum from August to October, but is present from at least April to December in southern Lake Huron (Schelske et al., 1976; Stoermer and Kreis, in press).

Low population densities of this species were observed in Green Bay (Fig. 27) during May, increasing in August and October with populations commonly exceeding 30 cells/ml. It did not respond positively to conditions south of Chambers Island as did several other diatom taxa, but higher densities were observed in the northwest nearshore area and in the Bay de Noc complex.

Stephanodiscus minutus Grun. *ex* Cleve and Möll.--

This species was commonly found in eutrophied nearshore areas and harbors in Lake Michigan (Stoermer and Yang, 1969) and with high densities in Lake Ontario from March to June (Stoermer et al., 1975). Populations apparently develop best in eutrophic to mesotrophic conditions. Stoermer et al. (1978)

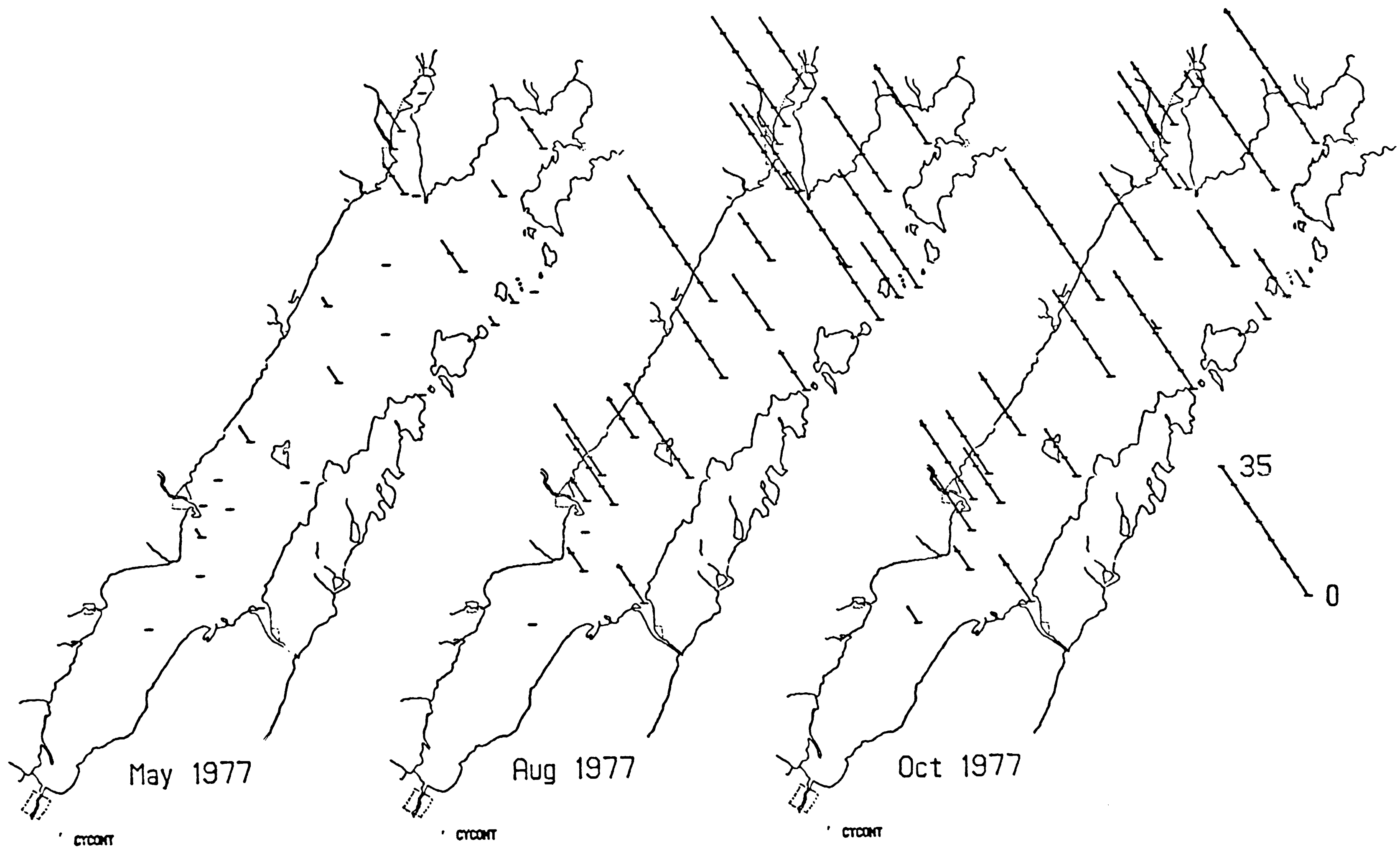

FIG. 27. Population densities of <u>Cyclotella comta</u>.

have found that it responds opportunistically with nutrient enrichment.

In Green Bay (Fig. 28) an unusually large population, about 150 cells/ml, developed at location 9 in May, while densities in the rest of the bay were less than 10 cells/ml. Its numbers increased slightly by August, exclusively at stations south of Chambers Island. October densities were the largest, remaining substantially larger in the southern half of the sampling region. Consistent positive correlations with alkalinity, .77 and .55, were found in August and October.

Stephanodiscus niagarae Ehr.--

Substantial populations have been reported from Green Bay. Its July distribution was restricted to the nutrient rich area from the Fox River to Chambers Island (Holland and Claflin, 1975). A northern Green Bay study reported sizable densities south of Chambers Island, near Portage Marsh, and in the Bay de Noc complex (Tierney et al., 1976). This taxon apparently grows best in eutrophic conditions.

In our sample (Fig. 29) it was sporadically recorded south of Chambers Island and in Little Bay de Noc during May and August. Its densities developed substantially in August to 150 to 350 cells/ml south of Chambers Island and in Little Bay de Noc.

Stephanodiscus sp. 8.--

This entity is very similar to and may be a form of *Stephanodiscus alpinus* Hust. *ex* Huber-Pestalozzi. This taxonomic relationship is currently being investigated. In Green Bay (Fig. 30) populations were only observed in October, primarily south of Chambers Island and at several stations in Little

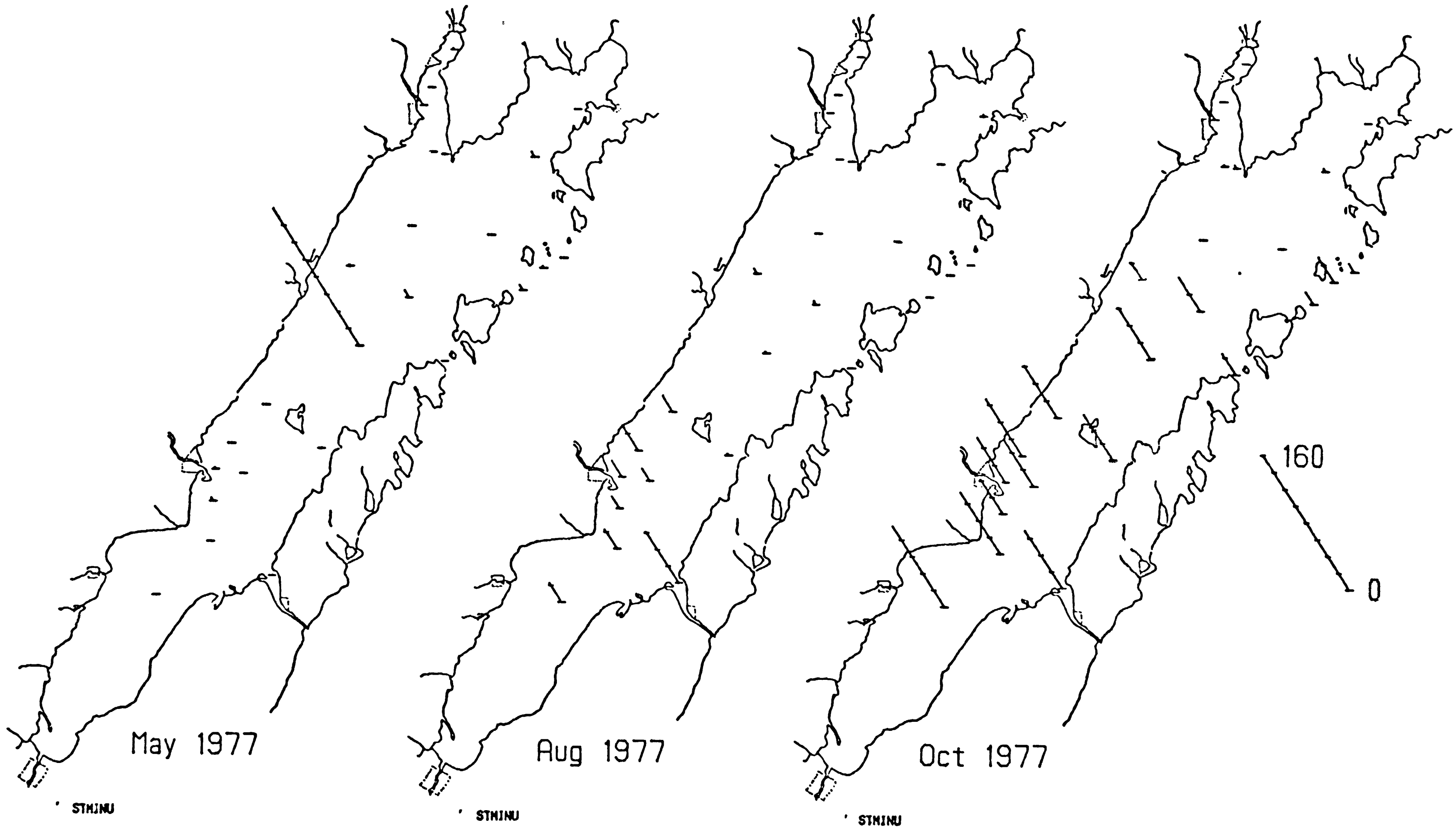

FIG. 28. Population densities of <u>Stephanodiscus minutus</u>.

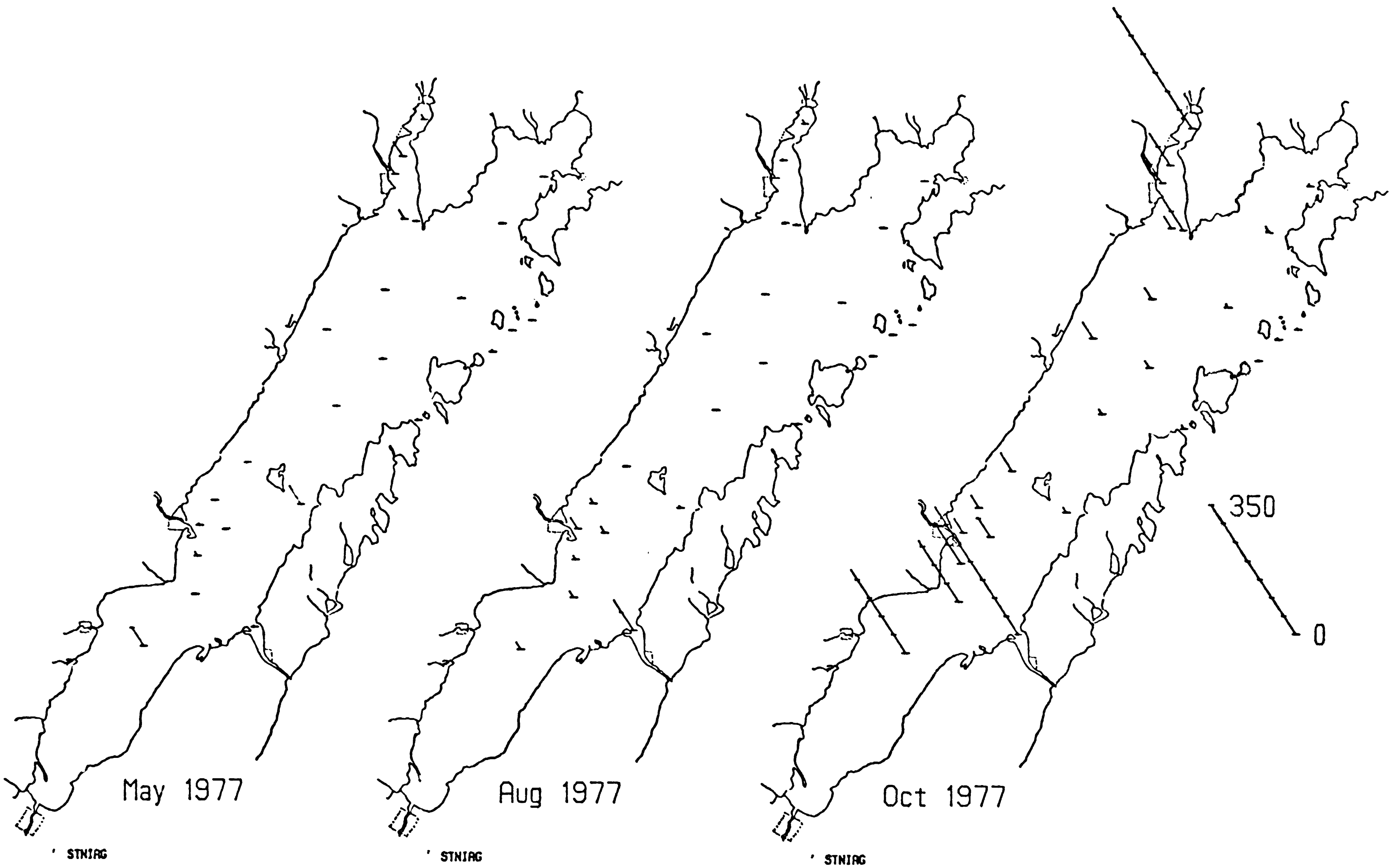

FIG. 29. Population densities of Stephanodiscus niagarae.

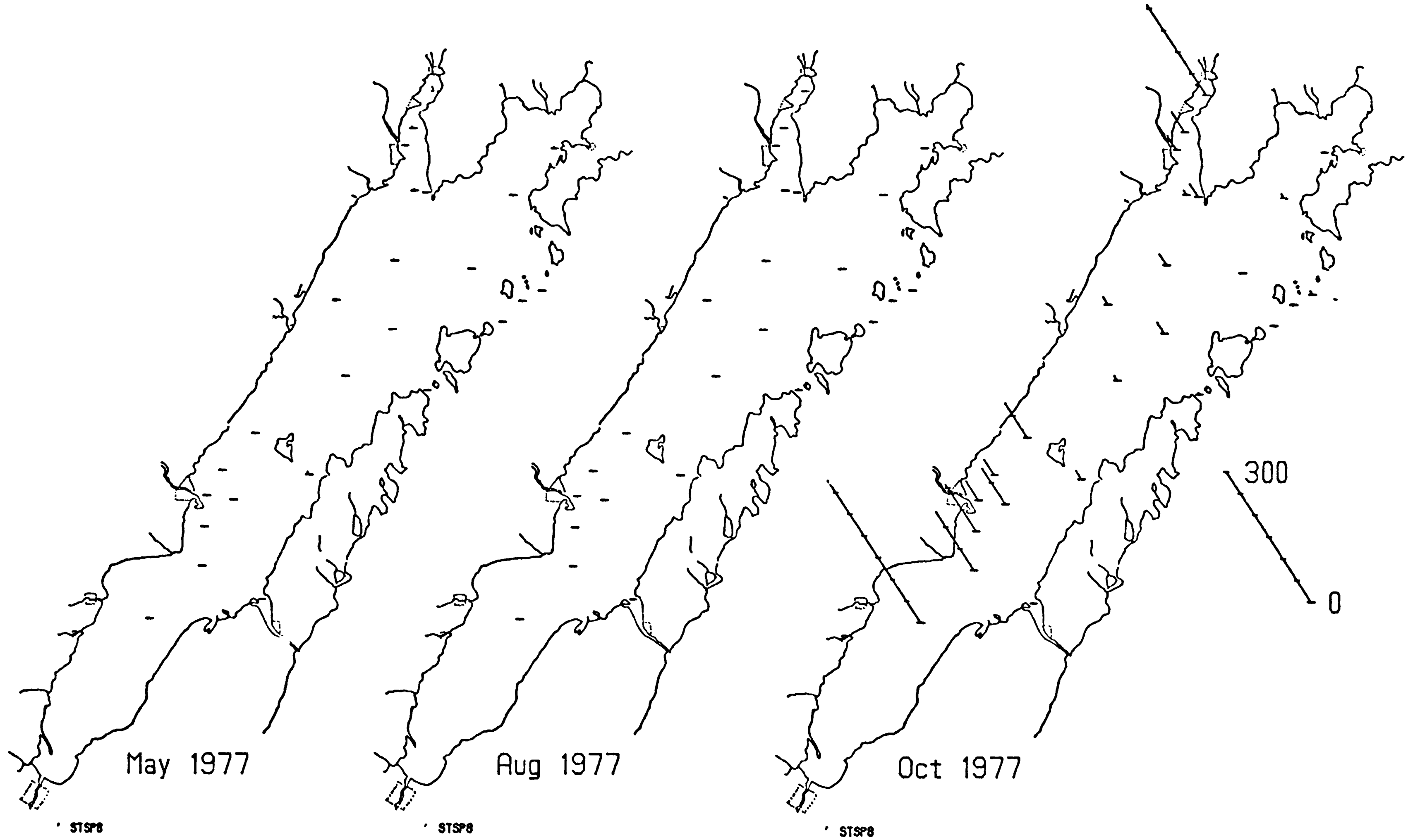

FIG. 30. Population densities of <u>Stephanodiscus</u> sp. 8.

Bay de Noc. It seems to respond to more eutrophic conditions.

Asterionella formosa Hass.--

Described as eurytopic (Schelske et al., 1976) and abundant in the Straits of Mackinac and northern Lake Huron nearshore areas in September and October, this taxon is truly ubiquitous. Huber-Pestalozzi (1942) reports its occurence in a wide variety of habitats. Hohn (1969) observed no change in its absolute abundance in Lake Erie from 1938 to 1965. Lowe (1974) summarizes it as alkaliphilous, tolerant of small amounts of total dissolved solids, cosmopolitan, oligosaprobic to beta-mesosaprobic with a summer maximum.

In Green Bay (Fig. 31) population densities are sporadic and low in May. In August it is present throughout the bay, with populations regularly exceeding 100 cells/ml only south of Chambers Island. In October it reached its maximum average density and was noticeably more abundant near the Menomimee River mouth, nearshore in northwest Green Bay, and in the Bay de Noc complex.

Tabellaria fenestrata (Lyngb.) Kütz.--

Abundant throughout most of the Great Lakes and other freshwater systems, this taxon is apparently eurytopic. Its abundance has not changed in Lake Erie from 1938 to 1965 (Hohn, 1969). Stoermer and Ladewski (1976) assign it a wide temperature tolerance with an optimum in southern Lake Michigan of 15°C. It has been suggested that this taxon suffers depressed populations in severely perturbed areas such as southern Green Bay (Stoermer and Yang, 1970). Koppen (1978) assigns this taxon to oligo-dystrophic waters.

In Green Gay (Fig. 32) this taxon was most abundant around the Menominee River in August. At all other locations and during the other sampling periods

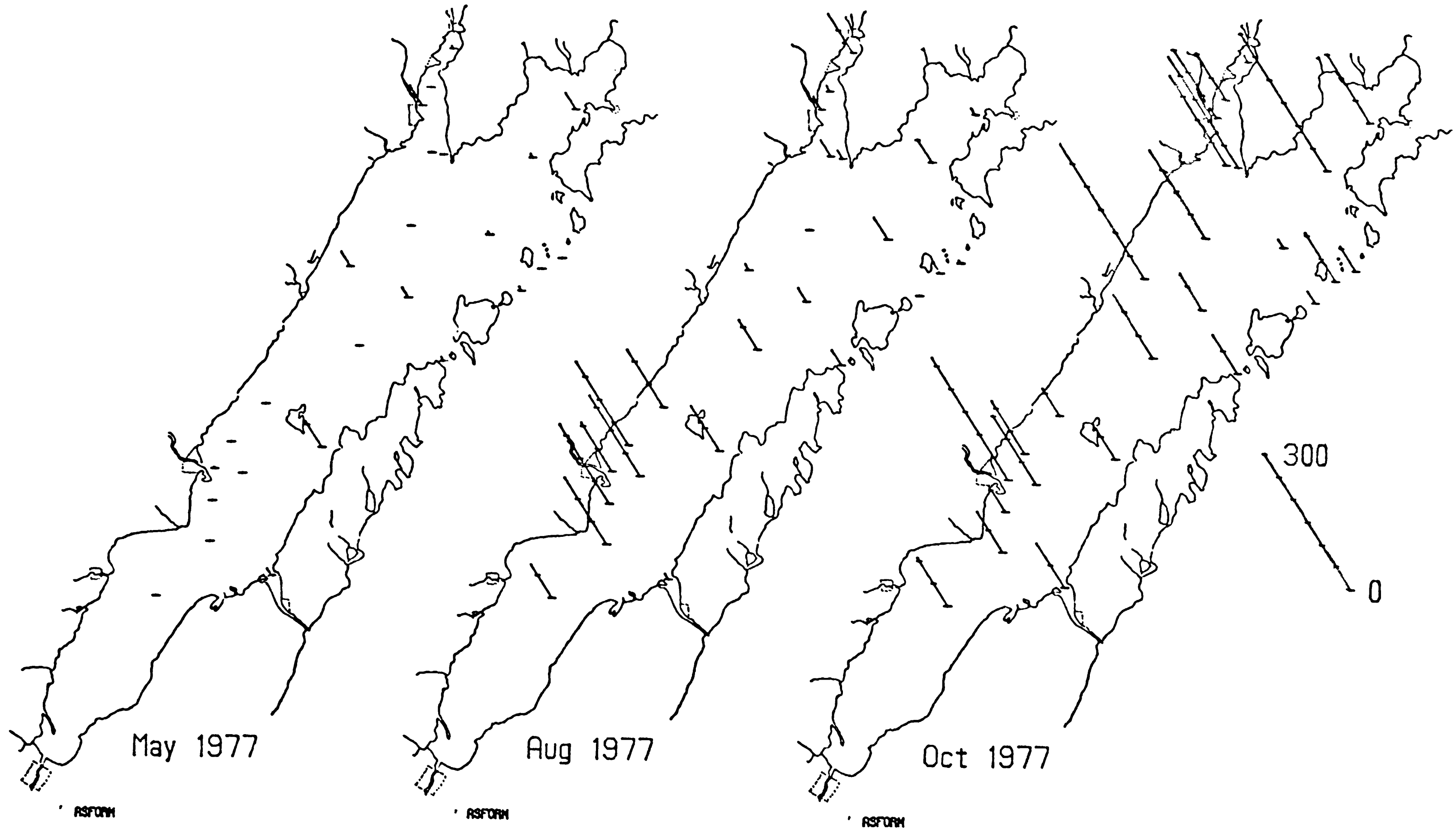

FIG. 31. Population densities of *Asterionella formosa*.

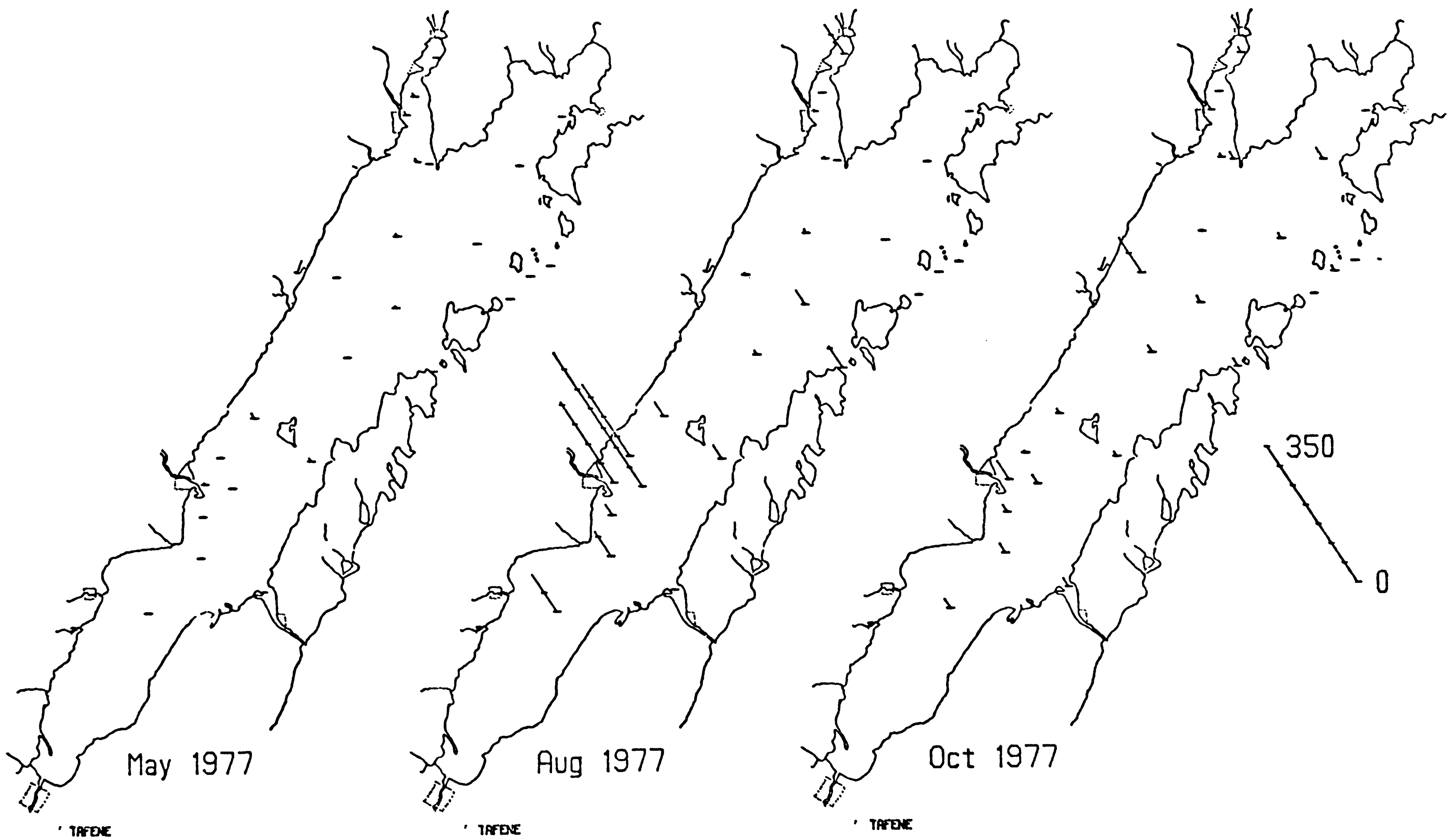

FIG. 32. Population densities of *Tabellaria fenestrata*.

population densities were much less.

Tabellaria flocculosa var. *linearis* Koppen--

This taxon has a peak abundance in May and June in Lake Huron, primarily nearshore (Stoermer and Kreis, in press). Koppen (1978) suggests this is a hard water species that develops best in mesotrophic to eutrophic habitats.

In Green Bay (Fig. 33), populations were very low in May, increased in August, and declined again in October. The largest densities, some exceeding 160 cells/ml, were observed at locations south of Chambers Island in August.

Fragilaria capucina Desm.--

Described as an important component of littoral phytoplankton in eutrophic lakes (Huber-Pestalozzi, 1942), this taxon has been abundant in western Lake Erie since 1950 (Hohn, 1969). Historically, densities of this taxa have been low in Lake Michigan (Stoermer and Yang, 1969). It has been noted as abundant in eutrophic areas of the Great Lakes such as southern Green Bay (Holland and Beeton, 1970; Holland and Claflin, 1975), Saginaw Bay (Schelske et al., 1974; Stoermer and Kreis, in press) and Lake Ontario (Stoermer et al., 1975). It is apparently most abundant during the summer. Lowe (1974) similarily describes it as alkaliphilous, eutrophic, indifferent to low levels of total dissolved solids, oligosaprobic, and eurythermal with a spring maximum.

In Green Bay (Fig. 34), it was only abundant in August and October and south of Chambers Island. Strong correlations with conductivity were noted in all three seasons.

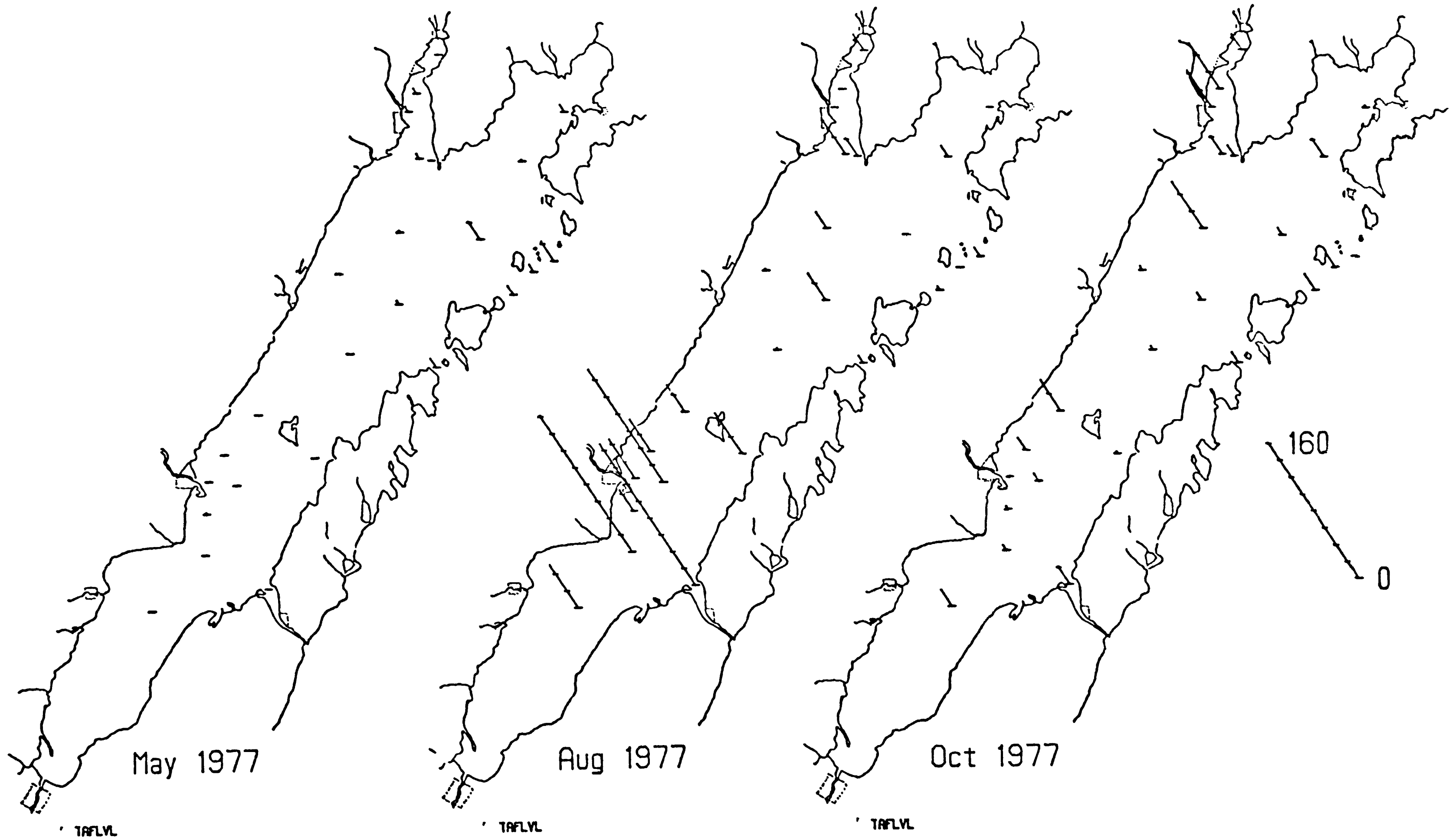

FIG. 33. Population densities of Tabellaria flocculosa var. linearis.

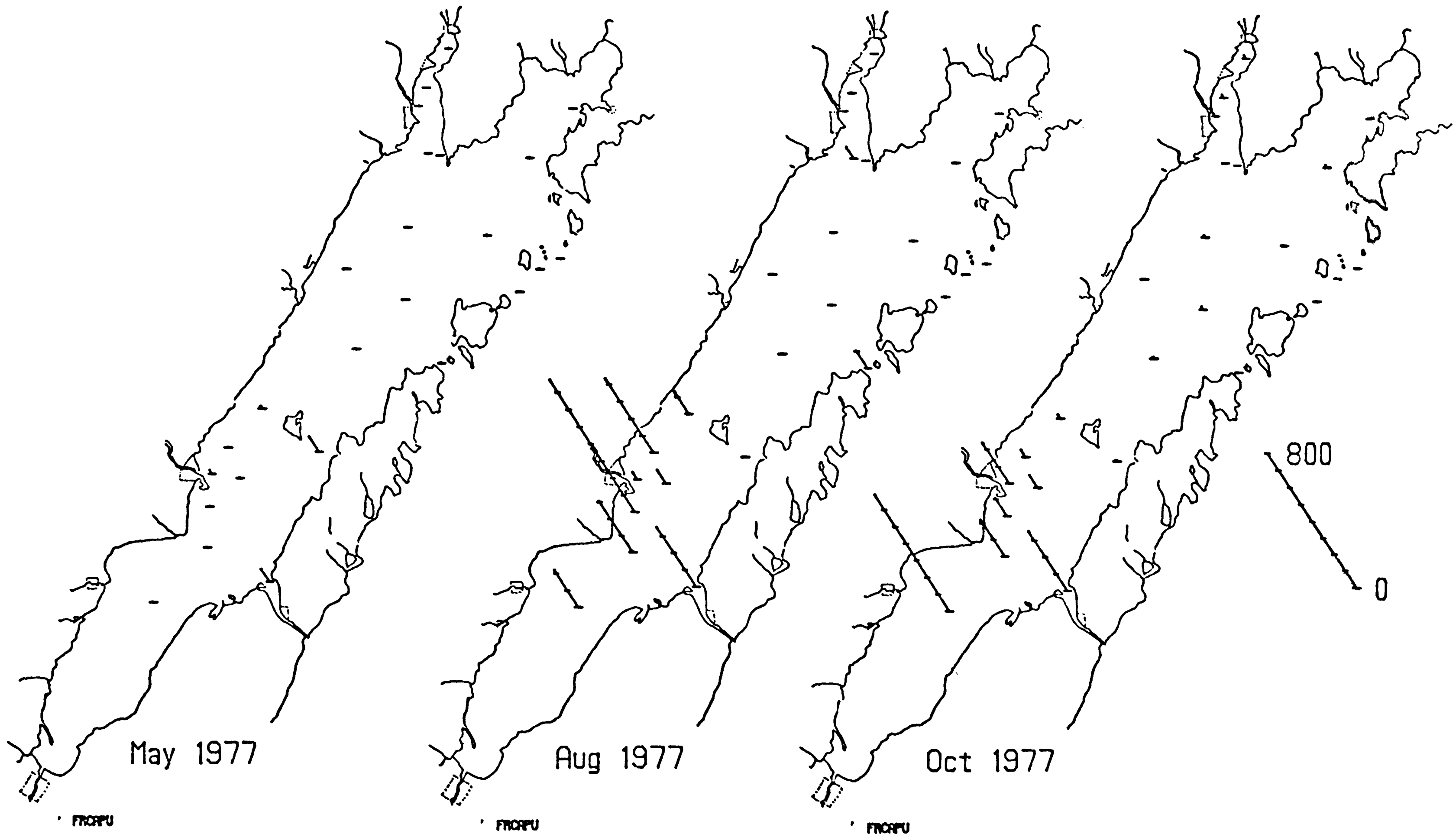

FIG. 34. Population densities of *Fragilaria capucina*.

Fragilaria crotonensis Kitton--

This species is tolerant of a wide range of ecological conditions. It has been proposed that this morphological entity may actually comprise several physiolgical races (Stoermer and Yang, 1969), enabling it to be so eurytopic.

In Green Bay (Fig. 35), its populations were sporadic, but fairly uniform throughout the bay during all sampling periods.

Synedra filiformis Grun.--

This taxon is apparently eurytopic. It has been noted in Lake Huron from May to early June and October in nearshore areas and around the mouth of Saginaw Bay (Schelske et al., 1974, 1976; Stoermer and Kreis, in press). Its Lake Michigan populations have primarily been offshore (Stoermer and Yang, 1969) and as part of the spring maximum in Grand Traverse Bay (Stoermer et al., 1972). Holland and Claflin (1975) found it in Big Bay de Noc region of Green Bay in June. Tierney et al. (1976) listed it with large densities in May.

In Green Bay (Fig. 36) population densities were high in the north in May, high in the south in August and abundant throughout most of the bay in October. Lower densities were characteristic for the central open bay region along the Lake Michigan interface.

Amphipleura pellucida Kütz.--

Stoermer and Yang (1970) report this taxon as widespread in Lake Michigan with low densities. Stoermer and Ladewski (1976) assign it a double temperature optimum of 3-6 and 15-17^{o}C. It has been reported as planktonic in Green Bay (Holland, 1969; Holland and Claflin, 1975), with densities reaching

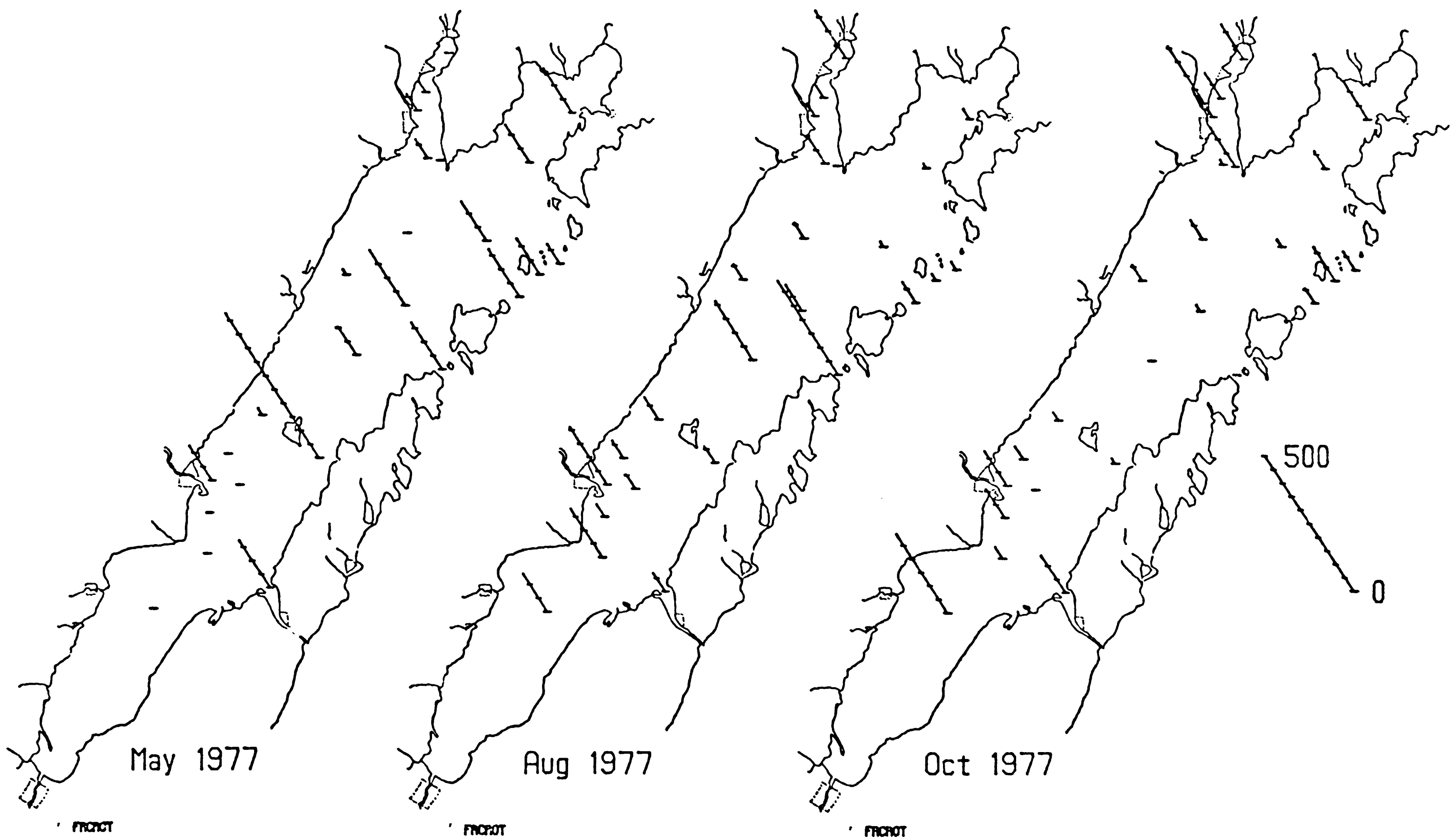

FIG. 35. Population densities of <u>Fragilaria crotonensis</u>.

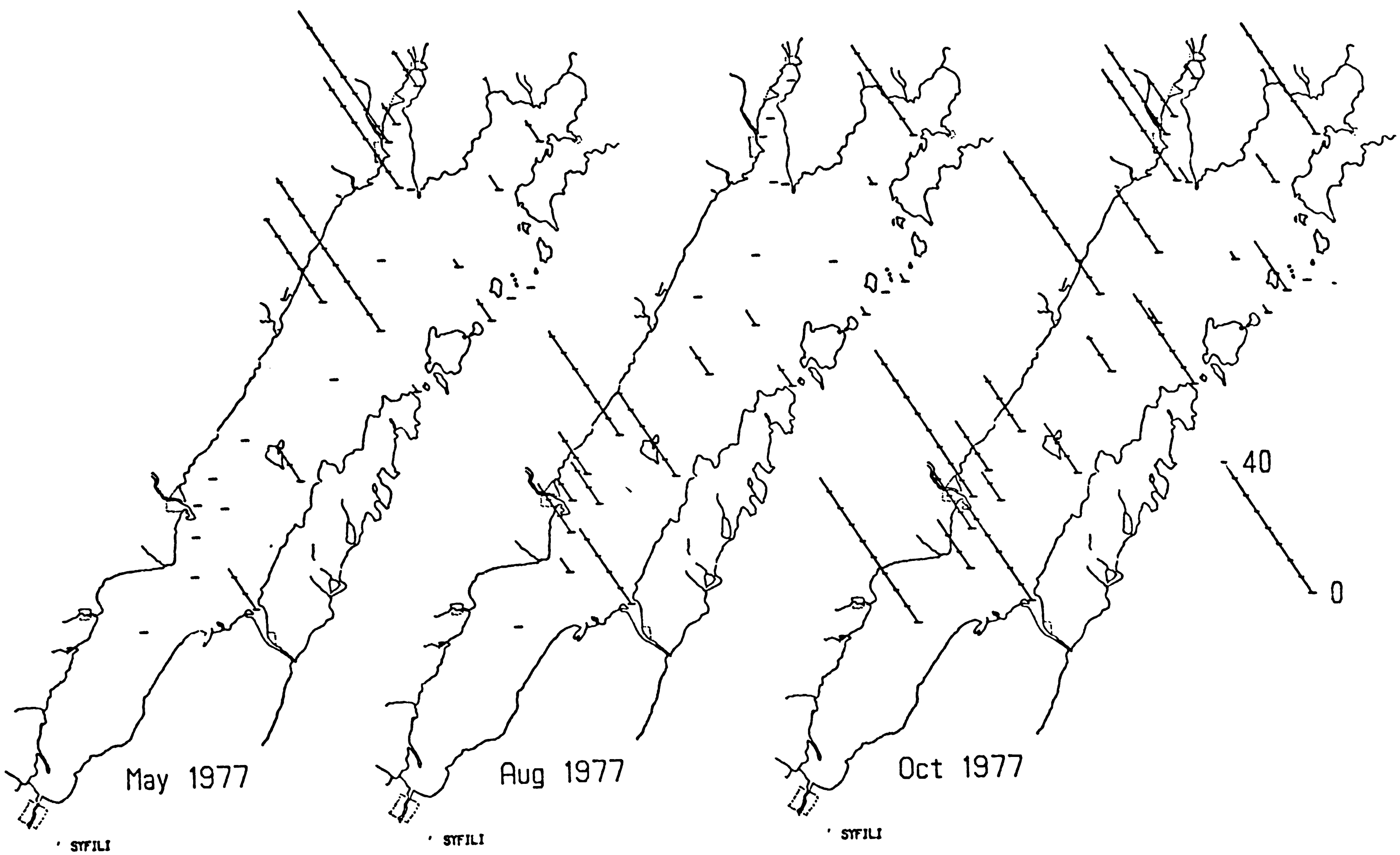

FIG. 36. Population densities of *Synedra filiformis*.

15-20 cells/ml in the area east and south of Chambers Island during July. Hustedt (1937-1939) describes this taxon as eutrophic.

In Green Bay (Fig. 37) this species was absent in May. It appears south of Chambers Island almost exclusively in August with low densities averaging about 10 cells/ml. October populations occur throughout the bay but are distinctly greater around and south of Chambers Island, surpassing densities of 70 cells/ml. This taxon apparently responds to more nutrient rich environments.

Nitzschia aciculariodes Archibald--

Populations of this taxon have been observed in Lake Michigan near Waukegan. It is probably more abundant than is reported in the literature because of its taxonomic obscurity. In Green Bay, (Fig. 38) populations were observed sporadically in May and only south of Chambers Island in August. In October it was present at lower population densities than August throughout the bay.

Chrysosphaerella longispina Lautb.--

Skuja (1948) reported this species from more or less dystrophic lakes and predominately in the summer and fall. He amended its distribution to numerous everywhere (Skuja, 1956) especially in the summer. This taxon was reported from northern Lake Huron (Schelske et al., 1976) and was sporadically abundant in Saginaw Bay in August to October (Stoermer and Kreis, in press).

In Green Bay (Fig. 39) it was most abundant in August in the south-central part of the bay at location 16, near the Menominee River, and in the Bay de Noc complex. Slightly lower August densities were recorded for

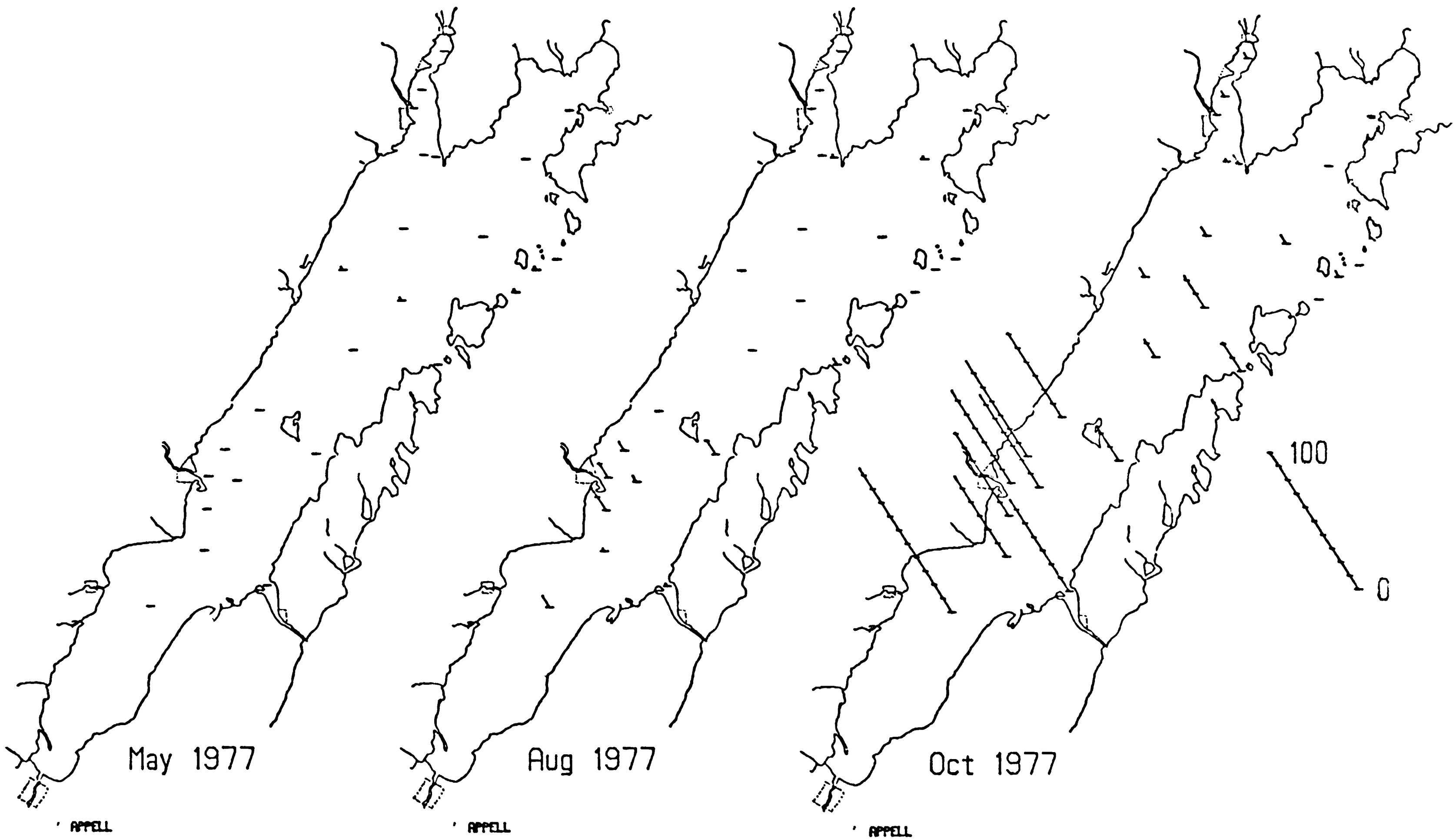

FIG. 37. Population densities of <u>Amphipleura pellucida</u>.

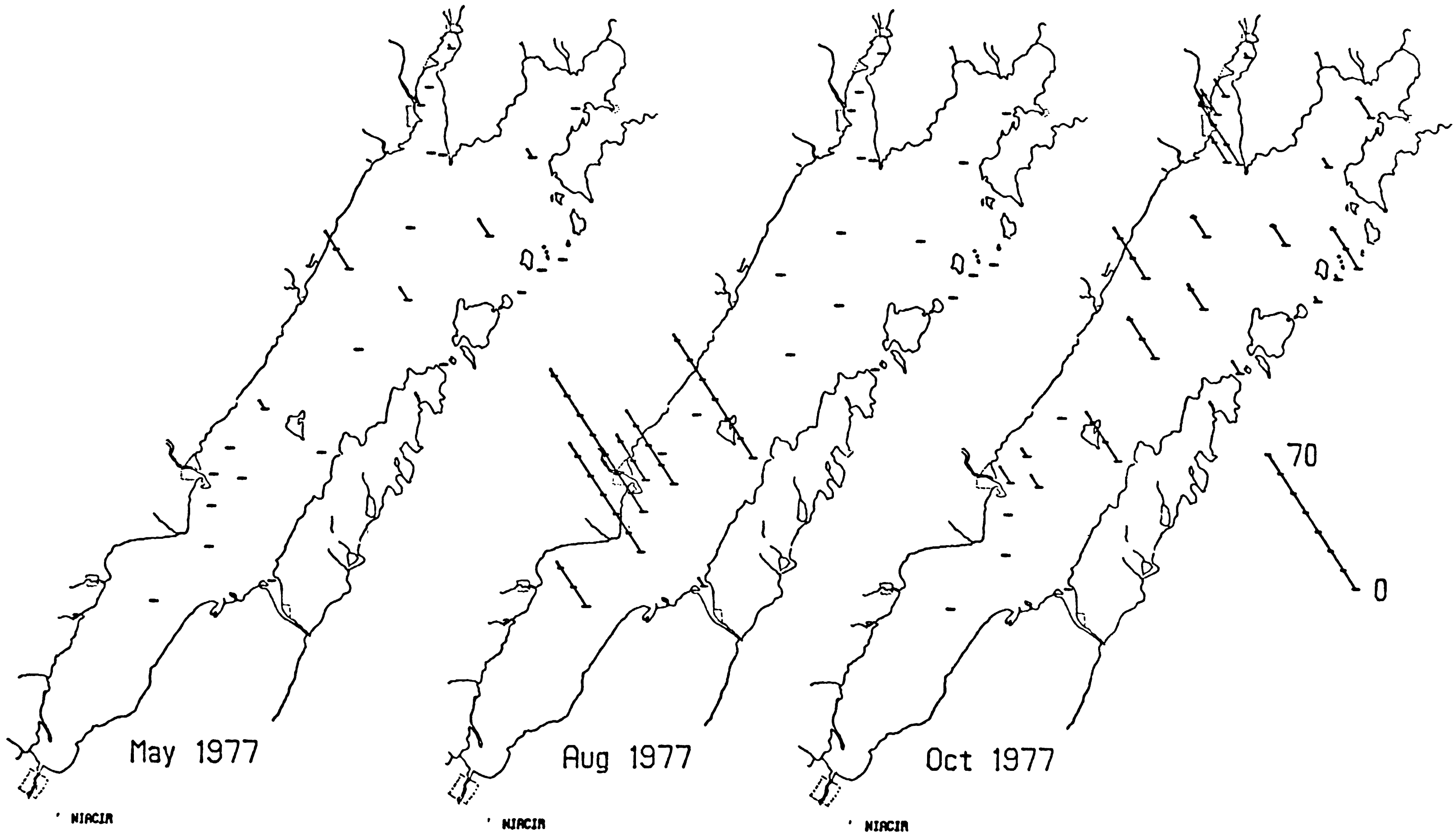

FIG. 38. Population densities of Nitzschia aciculariodes.

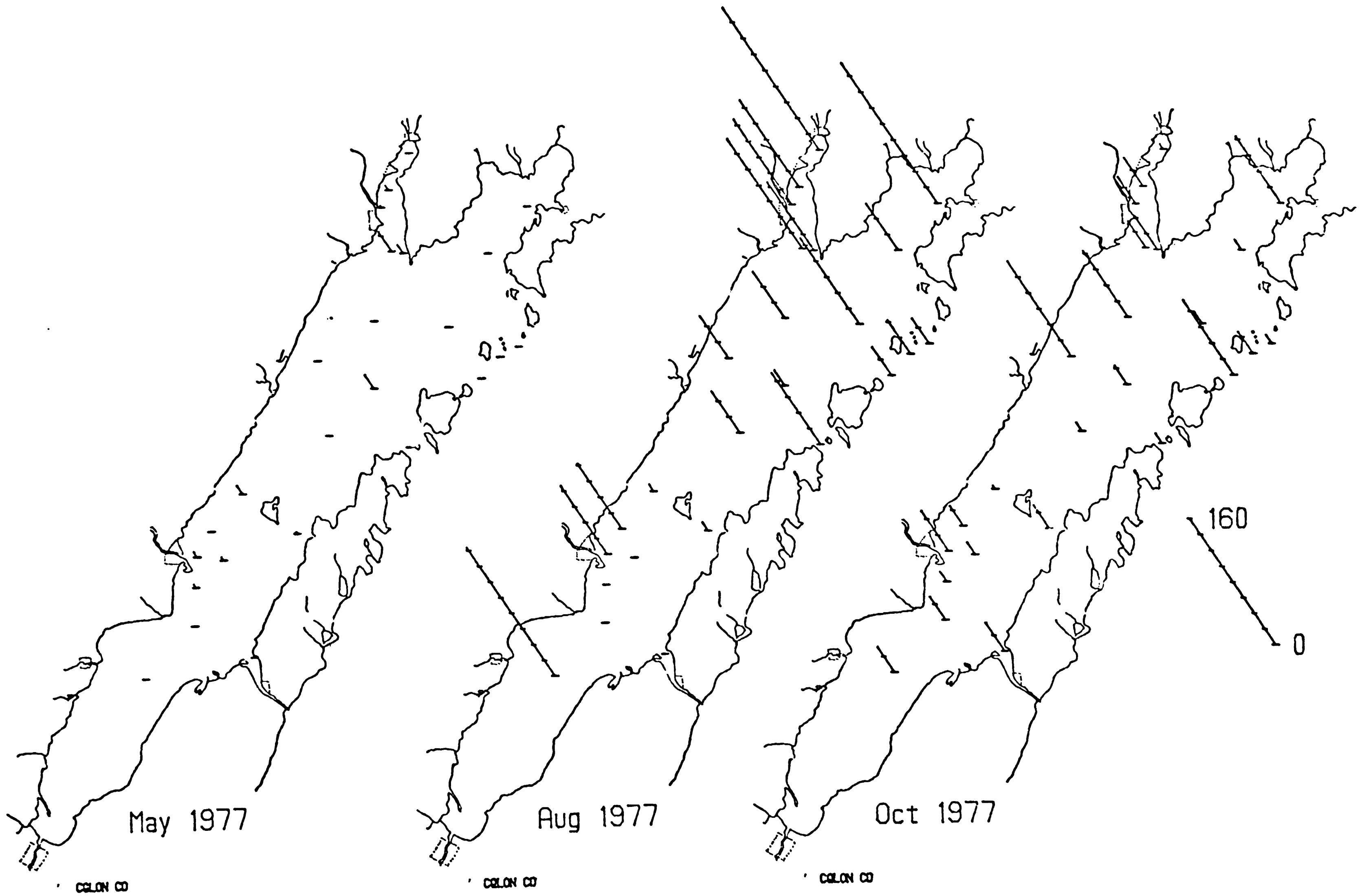

FIG. 39. Population densities of _Chrysosphaerella longispina_.

north-central Green Bay. Moderate densties were observed of the species in October, being slightly higher in nearshore waters around the northern shores of Green Bay. This taxon apparently has an affinity for more eutrophic conditions, especially during the summer.

Mallomonas pseudocoronata Presc.--

This taxon has been described as fairly rare with predicted maximum densities of 20 cells/ml in a 17-18°C temperature optimum (Stoermer and Ladewski, 1976). It was not observed in the May samples from Green Bay (Fig. 40), but did occur sporadically in August and October. The largest population densities were recorded in October at locations south of Chambers Island.

Chroomonas spp.--

These organisms have only recently been recognized as part of the Great Lakes flora. They were a common component in the phytoplankton of southern Lake Michigan (Stoermer and Tuchman, manuscript). In Green Bay (Fig. 41) it was sporadically represented in May and August. October populations were more uniform and were consistently greater in the area of the bay south of Chambers Island.

Rhodomonas minuta Skuja--

Skuja (1948, 1956) reported it as often abundant and usually with many other phytoplankton. This species has been observed throughout the Great Lakes. In Green Bay (Fig. 42) it was a primary component of the phytoplankton assemblages throughout the bay during all sampling periods. Only two blooms greater than 2000 cells/ml were recorded, both in August in the southern part

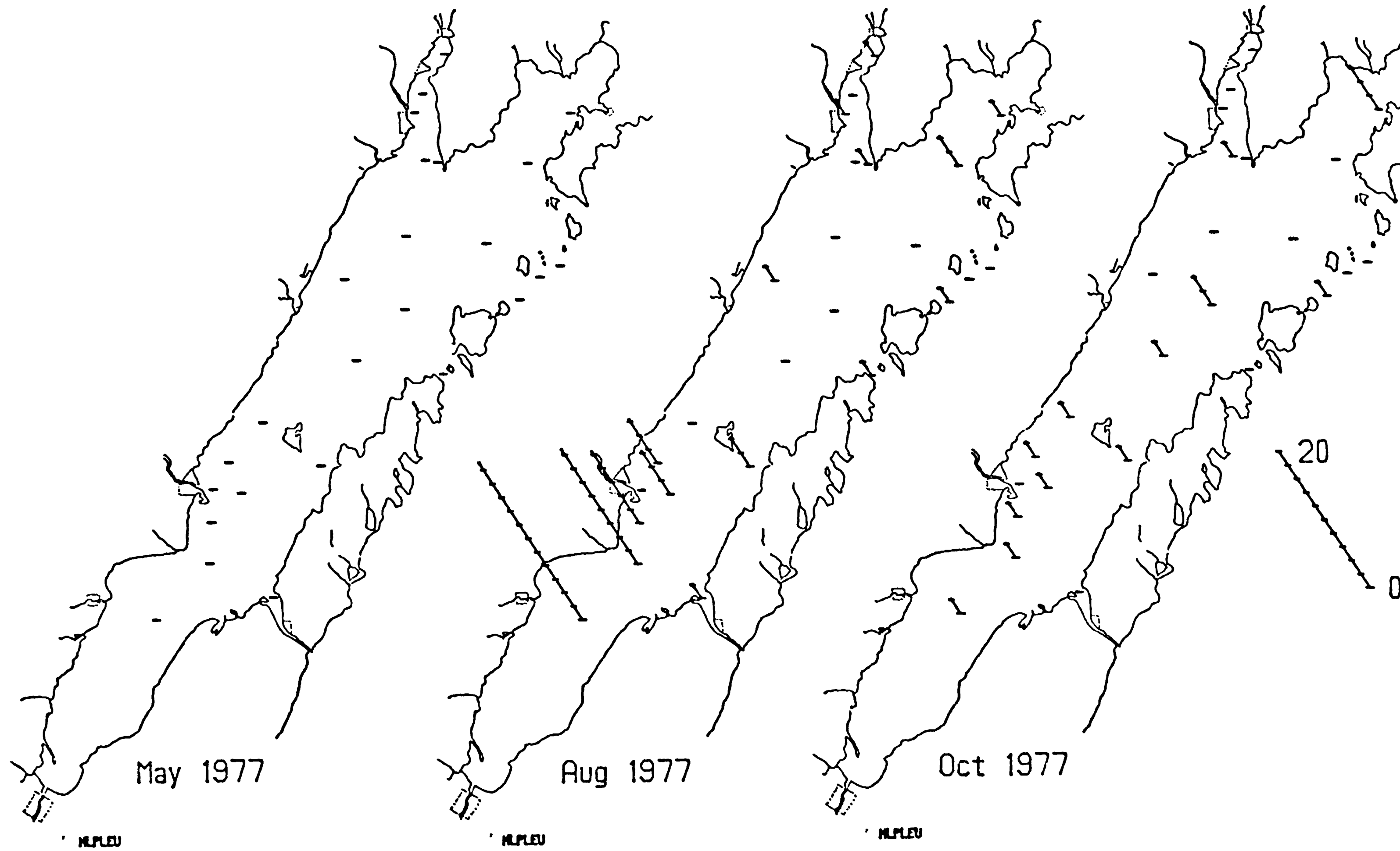

FIG. 40. Population densities of <u>Mallomonas pseudocoronata.</u>.

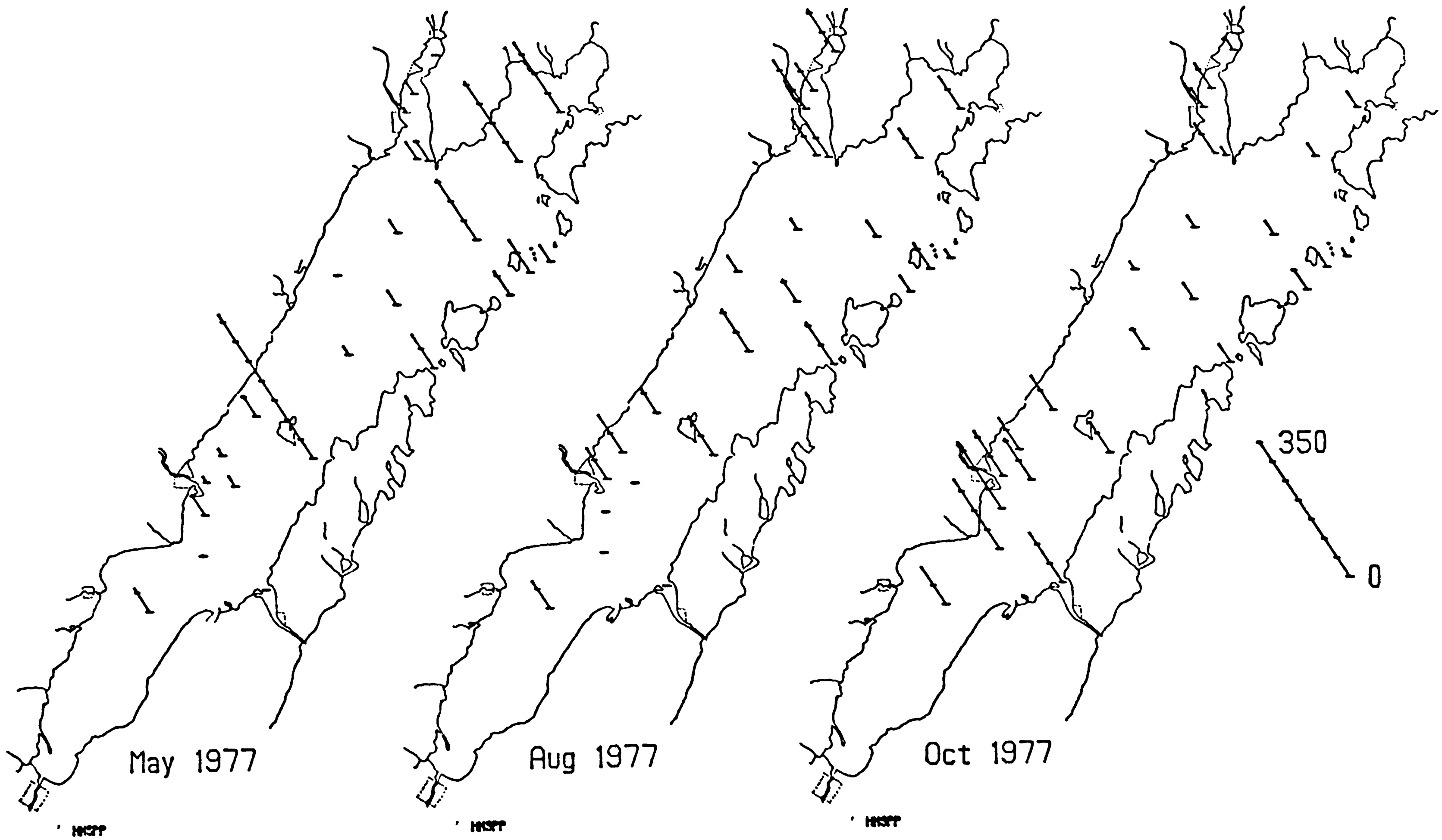

FIG. 41. Population densities of Chroomonas spp.

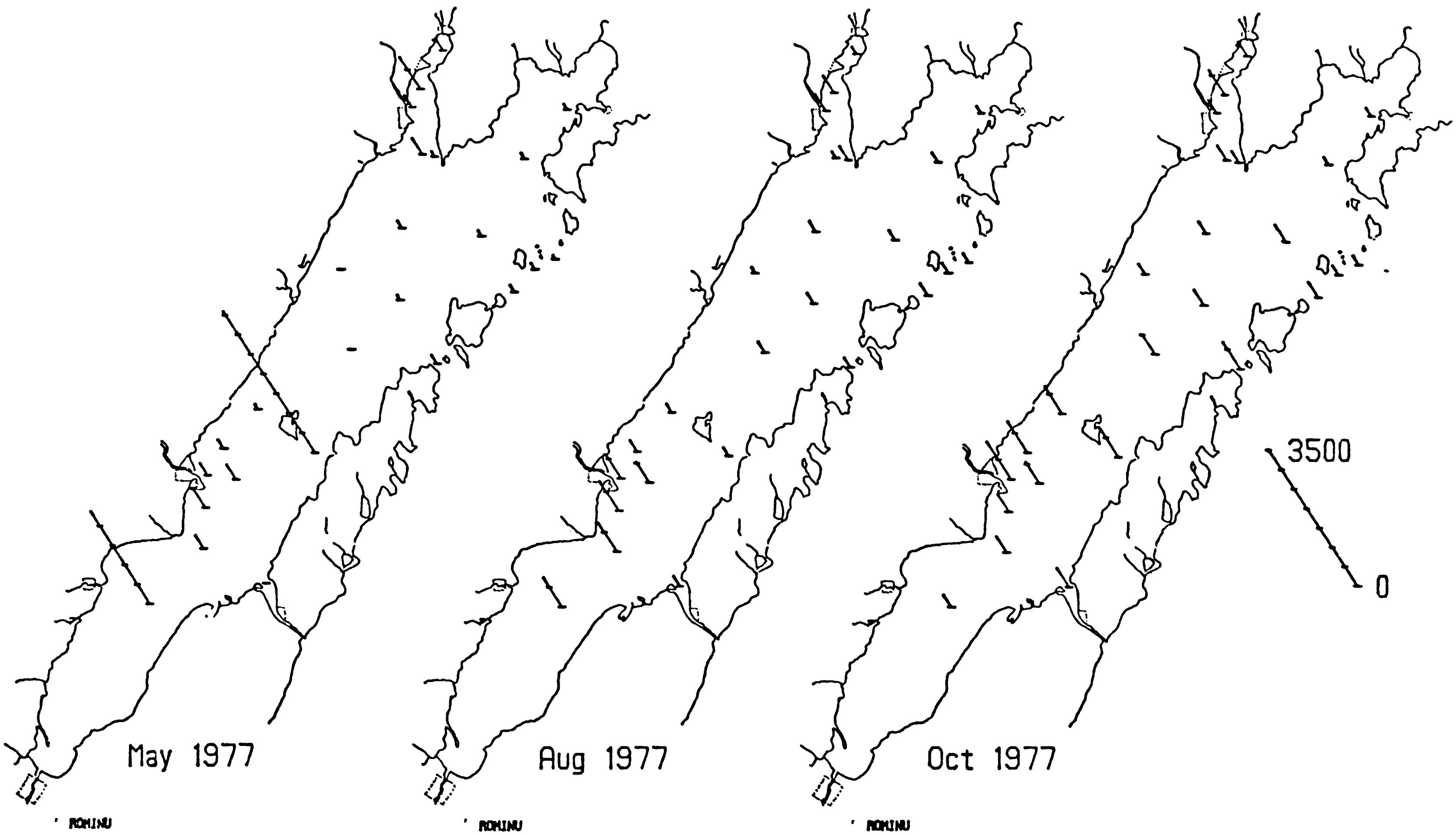

FIG. 42. Population densities of Rhodomonas minutus.

of the bay. Populations tended to be reduced north of Chambers Island in the open bay area.

Cryptomonas spp.--

C. marssonii, *C. ovata*, *C. erosa*, and *C. gracile* were identified members of this group. Due to taxonomic uncertainties these taxa were lumped for final analysis. They were present during all sampling periods in Green Bay (Fig. 43) with greatest densities south of Chambers Island. As a group they apparently are most abundant in more eutrophic waters. These organisms correlated positively with conductivity in August and October with values of .79 and .64.

Gymnodinium spp.--

This taxonomic group comprised various small dinoflagellates, probably from the genera *Gymnodinium*, *Glenodinium* and *Peridinium*. In Green Bay (Fig. 44) they were abundant during May in the northern part of the Bay and in Little and Big Bays de Noc. Large population densities persisted through August, but were notably higher south of Chambers Island and more moderately abundant throughout the rest of the bay. October densities were lower.

Microflagellates--

This group of organisms contains a taxonomic labyrinth of small flagellated solitary cells that probably include haptophytes, taxa of the genera *Pedinomonas* and *Ochromonas*, and various other Chlorophycean, Cryptophycean and Chrysophycean forms. Such a group has been observed in Lake Ontario with lower densities from April to June, when they bloomed to

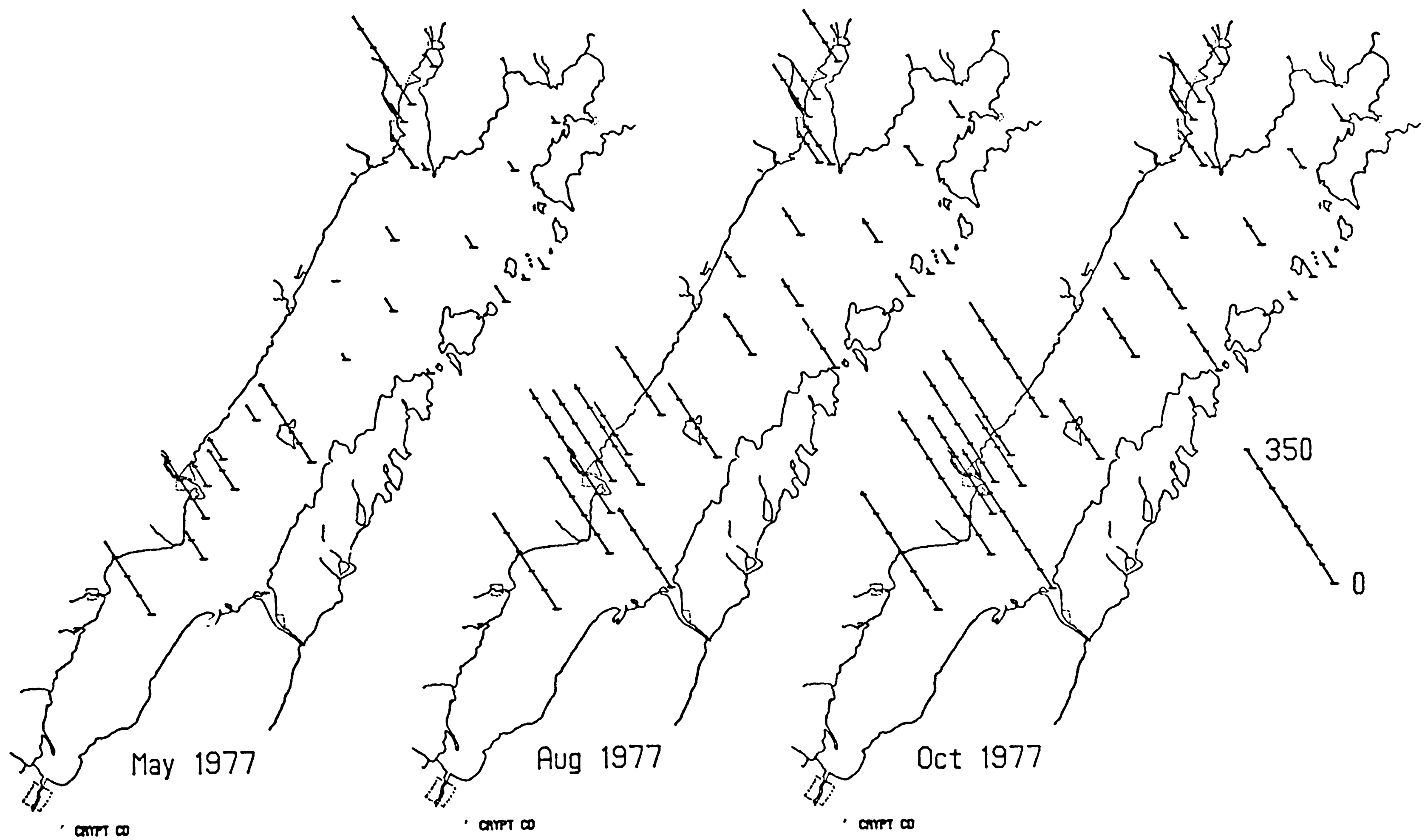

FIG. 43. Population densities of *Cryptomonas* spp.

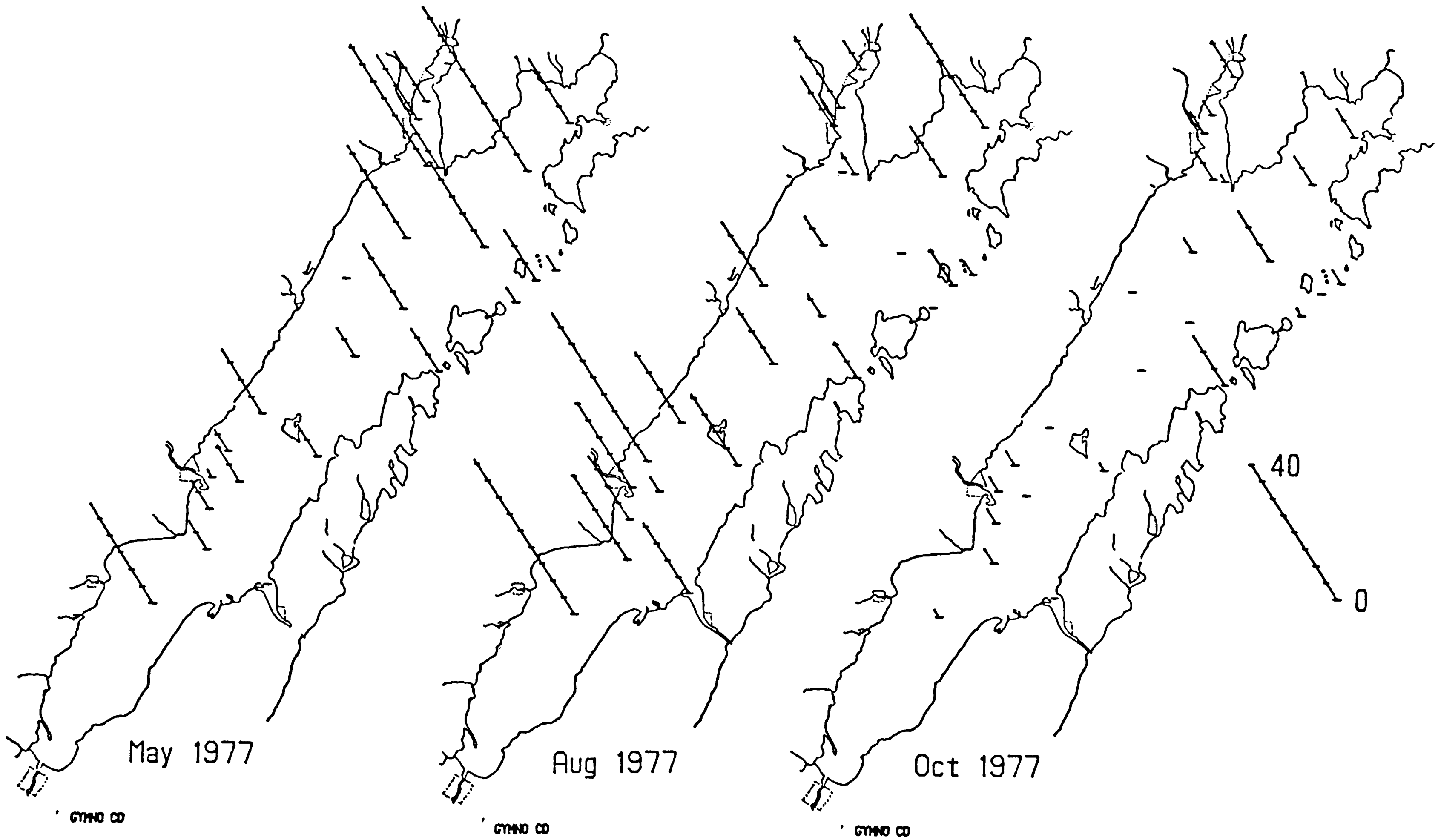

FIG. 44. Population densities of Gymnodinium spp.

densities as great as 5000 cells/ml (Stoermer et al. 1975).

In Green Bay (Fig. 45) they were observed with densities of up to 1000 cells/ml in May and October, but were most abundant in August, surpassing 2000 cells/ml densities.

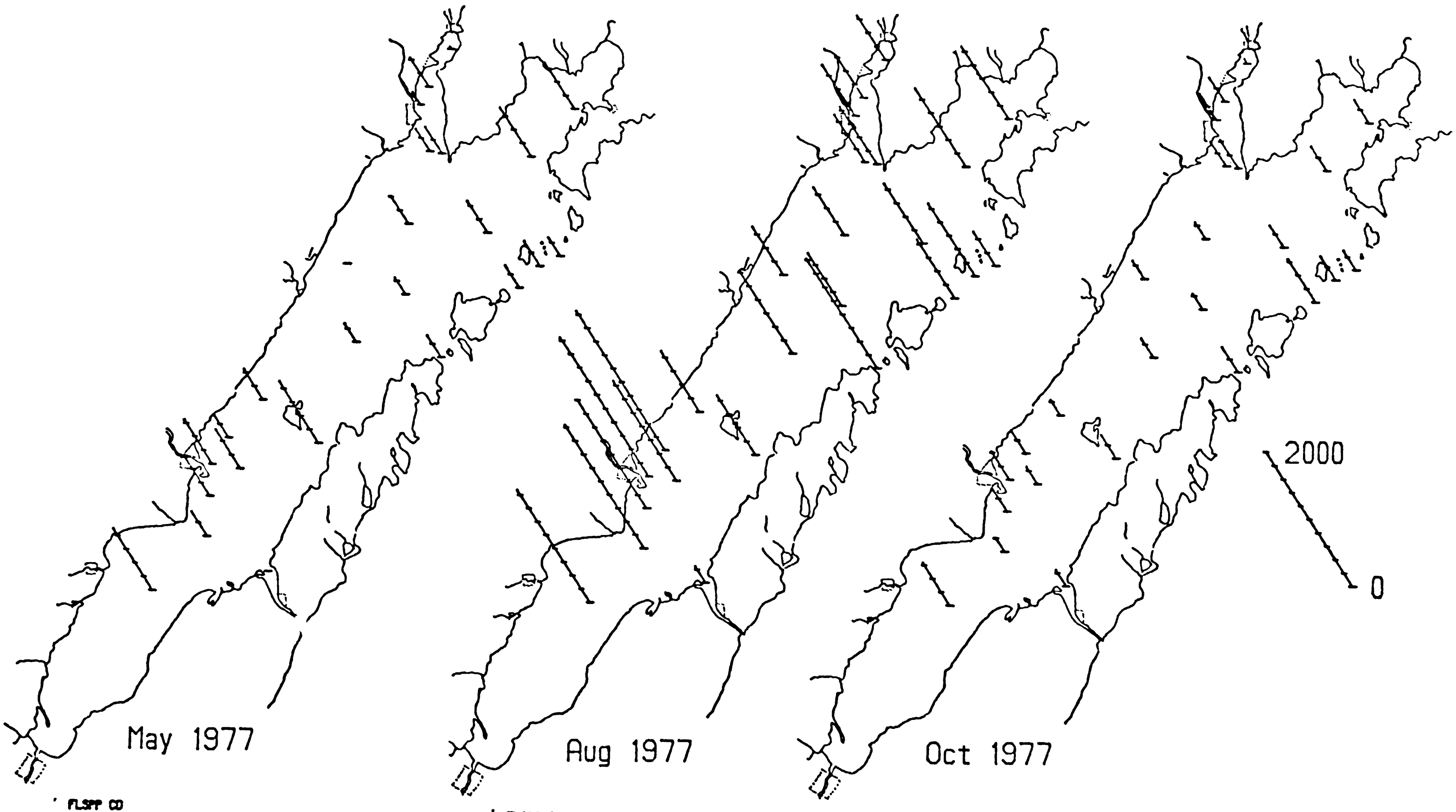

FIG. 45. Population densities of Microflagellates.

DISCUSSION

Green Bay receives the discharge of 1/3 of the total drainage basin of Lake Michigan and could be an important buffer for polluted water flushing into the relatively oligotrophic to mesotrophic water of northern Lake Michigan. Many of the undesirable properties of water pollution are the direct result of nutrient addition and the subsequent response of increased growth of phytoplankton. Strong evidence suggests that phosphorus is the nutrient limiting algal densities in the Lake Michigan basin. The distribution of the usable form of this nutrient is difficult to trace because phytoplankton assimilate it quickly and can utilize concentrations of phosphorus that are lower than can be readily detected. The distribution of variables in the system that are dependent upon phosphorus concentrations must therefore be examined. These variables include levels of other nutrients, phytoplankton community density, diversity, and composition, and phytoplankton population density.

Green Bay is apparently one of the most eutrophic areas of Lake Michigan. Holland (1968) describes the bay as eutrophic compared to the oligotrophic Wisconsin shore and the intermediate conditions on the Michigan shore of Lake Michigan. Tarapchak and Stoermer (1976) suggest the only regions more eutrophic than Green Bay would be a few harbors receiving heavy nutrient and industrial waste loadings directly from rivers. A southern Lake Michigan study (Stoermer and Tuchman, manuscript) which was done concurrently with this revealed an average phytoplankton density about 20% lower than the average for Green Bay.

The sampling regime in Green Bay was limited to north of the Oconto

River. Physicochemical variables such as pH, temperature, and ammonia and silica concentrations did not demonstrate recognizable patterns. This was more or less expected because only silica and nitrogen would have been directly affected by phytoplankton density. August and October conductivities did demonstrate a slight decreasing gradient from south to north. This could reflect either assimilation of the biologically active portion of the total dissolved solids or dilution with lower conductivity Lake Michigan water. This same gradient is evident for turbidity with an inverse gradient of the same distribution for Secchi depth and nitrate concentrations. The increased water transparency along the south to north longitudinal axis of the bay is probably due to a reduction of suspended solids. It does not correlate with phytoplankton density. The increase in nitrate is most likely a result of intrusion of Lake Michigan water which is less depleted in nitrate due to lower phosphorus loading and consequent lower phytoplankton densities.

The regions north and south of Chambers Island were recognized as major areas supporting substantially different phytoplankton associations. Little Bay de Noc also separated as a minor entity. The northwest nearshore area around Cedar River and Big Bay de Noc also displayed unique characteristics.

The northern bay region was characterized by regularly reduced populations of many species. Particularly, diatom densities were lower in August and October. Smaller abundances of the apparently eutrophic *Scenedesmus quadricauda* in August and October were also recognized. Blue-green algal densities were higher in August and lower in October than the other areas of the bay. Community similarity cluster associations clearly isolated this region from the south-central bay region.

The northwest nearshore area primarily separated from the northern bay

region on the basis of community similarity measured as euclidean distances. Unusually greater population densities of Cyclotella comta and Scenedesmus denticulatus var. linearis in August and October, Chrysosphaerella longispina in October, and Synedra filiformis in May and October delineated this station.

Big Bay de Noc featured indications of eutrophication, but without abundances of the species that usually characterize severely disturbed areas. Relatively higher abundances of chlorophycean algae, diatoms and the eurytopic Asterionalla formosa in October were apparent. Ample populations of Chrysosphaerella longispina accompanied the bloom of mesotrophic Cyclotella comensis in August. Location 25 was always considerably different than the rest of the bay, but location 24, closer to the main bay, clustered with the northern bay region in August.

Little Bay de Noc apparently suffered greater disturbance from waste loading than any other northern bay area. Large populations of green algae were observed here in October. The distinctly eutrophic Stephanodiscus niagarae and Cryptomonas spp. were very abundant in August, the latter in May and October, also.

The south-central bay region, south of Chambers Island, was characterized by the higher phytoplankton community abundance and eutrophic species densities throughout most of the sampled periods. The following distinctly eutrophic species were present in substantially higher density populations than the rest of the bay in August and/or October: Stephanodiscus minutus, Stephanodiscus niagarae, Amphipleura pellucida, Cryptomonas spp., and Fragilaria capucina. Green algae, total diatoms, Asterionella formosa, Tabellaria flocculosa var. linearis, Chrysosphaerella longispina, Chroomonas spp., and Mallomonas pseudocoronata also displayed higher densities south of

Chambers Island than in the northern open bay during their optimum season.

These surface phytoplankton associations do not agree entirely with the areas defined by Holland and Claflin (1975). It is significant that the upper bay was divided into two regions. Many of the diatoms reported as characteristic of the regions which Holland and Claflin delineated tend to agree with the flora of regions defined in this study. The spatial differences noted may be the result of a different hydrodynamic status of the bay due to transient meteorological conditions.

Examination of the phytoplankton community distributions utilizing euclidian distances and cluster analysis reveals temporally different balances within the large regional groupings. The northern and south-central bay regions are very dissimilar, being the last clusters to associate in August and October, but the magnitude and orientation of the dissimilarity distances are quite different within the groups for the two sampling periods. The August northern bay cluster extends into Big Bay de Noc to location 24 and seems to trap the Little Bay de Noc cluster tightly with the bay. In October the northern bay cluster does not include location 24 of Big Bay de Noc, and the Little Bay de Noc cluster spreads south with a north to south longitudinal axis along the northwest nearshore area. Long axes are also apparent in the three minor associations within the northern bay cluster. The respective presence and absence of these axes in October and August are substantiated by the shape of the euclidian contours oriented around location 7. These axes are oriented in a manner suggesting a circular circulation for the bay north of Chambers Island. The absence of these axes in August suggests this circulation was modified, possibly as a result of seich activity.

If a northern transport of water did exist as a result of a seiche,

several conditions could be expected. First, the water in the Bay de Noc areas would become isolated resulting from the movement of water toward them. This appears to be the situation in August, but not October. Second, water would exit Green Bay into Lake Michigan along the northern boundary. This can not be substantiated because of the lack of sampling locations in Lake Michigan. Third, the movement of water from south to north would decrease community dissimilarity distances between the southern and northern locations. These distances between location 16 and northern bay locations are indeed smaller in August than October. Last, if the water level lowered in southern Green Bay, Lake Michigan water and its phytoplankton assemblage would enter the bay from Sturgeon Bay. This is suggested by the greater August dissimilarities between location 17 and surrounding sampling locations compared to much smaller October dissimilarities. The phytoplankton communities seemed to have mapped a demonstration of substantially different hydrodynamic structures of the bay.

Green Bay remains as a eutrophic extremity of Lake Michigan. It seems to respond rapidly to different temporal hydrodynamic situations that develop. Waters of the south-central bay and Little Bay de Noc demonstrate symptoms of considerable eutrophication. The northern bay region is apparently less perturbed, which may be the result of biological reclamation of the water or dilution with Lake Michigan water.

CONCLUSIONS AND RECOMMENDATIONS

The results of this investigation epitomize some serious problems in our current approach to water quality management. Although the phytoplankton assemblages of northern Green Bay are generally characteristic of nutrient rich conditions, there are several different phytoplankton associations present which indicate response to varying types and intensity of perturbation. It is clear that development of most efficient management strategies depends on detection and proper evaluation of these more subtle system responses. On the basis of our results, several levels of effect can be recognized.

The flora of Big Bay de Noc is characteristic of naturally productive regions within the Great Lakes system. Although such regions maintain relatively high primary production rates and large phytoplankton standing stocks, they are generally not associated with water quality problems.

> *Since such naturally productive areas furnish important nursery areas for some fish species and are important to the function of the entire system, further study should be undertaken to understand their trophic dynamics. Big Bay de Noc would be an appropriate area for such a study since it is one of the few remaining such areas in the Great Lakes system which have not suffered extensive anthropogenic modification.

Our data show local areas of extreme perturbation in Little Bay de Noc near Escanaba, the Escanaba River, and on the western shore near the Menominee River; areas where severe water quality problems associated with eutrophication have occurred in the past.

> *Further remedial actions are necessary to reduce inputs from sources

in these areas.

Two primary zones of water quality are present in the open waters of Green Bay. Phytoplankton populations at stations south of the vicinity of Chambers Island are characteristic of highly perturbed conditions. Populations at stations north of this area reflect the influences of both nutrient reduction by loss to the sediments and dilution through exchange with Lake Michigan.

- *Further remedial action to limit nutrient input to southern Green Bay is clearly indicated.
- * Additional studies should be undertaken to quantify the exchange of water and dissolved and entrained materials between northern Green Bay and Lake Michigan proper.
- * Additional process oriented studies should be undertaken to quantify loss rates associated with phytoplankton populations generated in the highly eutrophic southern portion of Green Bay.

Data from the current project indicate that Green Bay is a very dynamic system and that it is highly probable that the temporal sequence of sampling is not adequate to resolve some important events.

- * Any subsequent studies of this system should include sampling during the spring phytoplankton maximum.
- * Additional information should be gathered regarding time series of population change in areas of the bay receiving differing nutrient levels.

The results of this project show continued population succession in the Lake Michigan system. Some phytoplankton populations now dominant (e.g. *Cyclotella comensis*) were either absent or very rare in the system until very recently. Other previously important populations have been effectively removed

from the phytoplankton assemblage.

* Continued biological monitoring of the system is necessary to detect trends resulting from biotic interactions which will not be detected by chemical and physical measurements alone.

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APPENDIX A. Physicochemical data for May composite and August and October discrete samples from Green Bay, 1977. It includes the location number (L), collection date (CD), collection depth (D, m), bottle temperature (T, C), alkalinity (A, ppm CO_3), specific conductivity (C, mohms), turbidity (X), nitrate and nitrite (N, ppm), ammonia (M, ppm), reactive silica (SI, ppm), and secchi depth (S, m). Reactive phosphorus concentrations were less than 2 ppb.

L	CD	D	T	A	C	X	N	M	SI	S
001	770505	09	10.2		238					2.0
002	770505	09	09.0		305					2.5
003	770505	11	10.0		320					1.0
004	770505	25	08.0		310					2.5
005	770505	12	06.4		320					5.0
006	770505	30	05.0		300					5.0
007	770517	30	05.0		318					5.5
008	770517	15	09.0		342					5.0
009	770519	32	10.2		365					5.5
010	770519	15	10.0		344					4.5
011	770504	15	05.0		310					-.-
012	770503	15	02.3		310					2.5
013	770504	26	04.5		000					4.5
014	770503	15	05.0		315					3.0
015	770504	16	06.0		280					3.0
016	770504	15	07.8		000					2.0
017	770518	15	18.4		460					2.0
018	770518	14	18.0		440					2.5
019	770518	30	11.0		380					5.0
020	770517	45	05.5		330					6.0
021	770517	30	05.8		320					6.0
022	770517	30	06.0		320					6.0
023	770517	30	07.0		338					6.0
024	770517	15	09.8		348					5.5
025	770517	12	13.1		362					4.5
001	770811	02	20.0	110	271	0.8	0.03	0.021	1.05	4.5
001	770811	10	20.0	110	273	0.9	0.04	0.023	1.18	4.5
002	770811	02	20.0	110	272	0.6	0.05	0.012	0.70	4.5
002	770811	14	18.0	109	278	1.0	0.09	0.040	1.65	4.5
003	770811	02	20.0	109	284	1.2	0.06	0.022	1.06	2.5
003	770311	12	19.0	110	279	1.4	0.07	0.034	1.12	2.5
004	770811	02	19.5	110	277	0.7	0.07	0.150	0.38	4.5
004	770810	15	18.5	110	276	0.9	0.08	0.320	0.66	4.5
005	770811	02	20.0	109	274	0.7	0.05	0.006	0.35	5.5
005	770811	12	20.0	109	274	0.7	0.05	0.006	0.35	5.5
006	770810	02	21.5	110	274	0.7	0.05	0.005	0.17	4.5
006	770810	16	18.5	110	276	0.8	0.08	0.015	0.33	4.5
007	770810	02	22.5	110	275	0.6	0.02	0.004	0.16	5.5
007	770810	30	10.0	110	274	0.9	0.17	0.017	0.90	5.5
008	770810	02	21.0	110	273	0.7	0.04	0.004	0.22	5.5
008	770810	10	20.5	110	274	0.8	0.05	0.008	0.28	5.5
009	770810	02	22.0	113	278	0.7	0.02	0.004	0.14	5.0
009	770810	33	09.0	110	277	0.9	0.22	0.017	1.60	5.0
010	770810	02	21.0	113	279	0.8	0.02	0.004	0.13	4.0
010	770310	2[illegible]	10.5	111	278	1.4	0.18	0.017	1.80	4.0
011	770810	02	21.5	113	280	0.8	0.02	0.003	0.13	3.0
011	770810	14	18.0	112	279	0.8	0.03	0.008	0.22	3.0
012	770810	02	21.0	113	281	1.0	0.02	0.003	0.13	2.5
012	770810	11	20.5	113	281	1.3	0.02	0.003	0.14	2.5
013	770810	02	20.0	113	279	1.0	0.02	0.040	0.17	2.5
013	770810	17	15.0	110	277	1.1	0.10	0.070	0.58	2.5
014	770810	02	21.0	114	282	1.1	0.02	0.050	0.13	3.0
014	770810	20	12.5	111	276	1.5	0.16	0.130	1.51	3.0
015	770810	02	20.0	113	280	1.0	0.02	0.004	0.18	3.0
015	770810	23	10.5	111	279	0.8	0.20	0.012	2.35	3.0
016	770810	2	21.0	113	283	0.9	0.02	0.004	0.17	3.0
016	770810	16	11.5	112	280	1.3	0.17	0.010	2.73	3.0
017	770810	2	10.0	116	278	1.0	0.20	0.007	2.30	3.0
017	770810	7	09.5	107	282	0.8	0.21	0.006	2.38	3.0
018	770810	02	22.0	113	278	0.7	0.02	0.004	0.16	4.0
018	770810	20	11.0	111	279	1.0	0.20	0.010	2.20	4.0
019	770811	02	20.0	112	277	0.6	0.02	0.003	0.15	4.5
019	770811	34	10.0	111	278	1.8	0.22	0.018	1.44	4.5
020	[illegible]	02	20.0	112	274	0.6	0.06	0.004	0.19	5.0
020	770811	37	10.0	112	276	1.0	0.23	0.020	1.73	5.0
021	770811	02	20.0	109	271	0.6	0.10	0.004	0.24	5.0
021	770811	21	15.5	110	270	0.7	0.14	0.012	0.28	5.0
022	770811	02	20.0	109	272	0.7	0.08	0.004	0.23	5.0
022	770811	11	20.0	109	271	0.6	0.08	0.006	0.24	5.0
023	770811	02	20.0	110	271	0.6	0.07	0.004	0.18	5.5
023	770811	23	12.0	110	275	1.0	0.18	0.016	1.23	5.5
024	770811	02	21.0	112	271	0.9	0.05	0.006	0.22	5.0
024	770811	17	15.5	111	275	1.0	0.12	0.028	1.18	5.0
025	770811	02	21.0	110	271	1.0	0.02	0.007	0.31	5.0
025	770811	08	20.5	110	271	1.0	0.02	0.005	0.31	5.0
001	771007	02	11.5	105	261	5.3	0.01	0.003	1.02	0.3
001	771007	07	12.0	104	261	5.2	0.01	0.002	1.21	0.3
002	771007	02	12.3	105	273	2.3	0.09	0.004	1.59	1.5
002	771007	10	12.5	106	274	2.2	0.09	0.002	1.55	1.5
003	771007	02	12.7	107	279	1.8	0.09	0.013	1.37	1.5
003	771007	10	12.8	107	275	2.0	0.09	0.010	1.39	1.5
004	771007	02	13.2	108	272	0.8	0.09	0.007	1.11	3.0
004	771007	17	13.0	108	274	0.9	0.09	0.008	1.12	3.0
005	771007	02	12.5	107	275	1.3	0.09	0.010	1.34	2.0
005	771007	10	12.8	107	273	1.6	0.09	0.011	1.35	2.0
006	771008	02	13.5	103	273	1.5	0.09	0.004	1.15	3.0
006	771008	15	13.5	105	273	2.9	0.10	0.004	1.16	3.0
007	771008	02	13.7	110	276	2.0	0.09	0.004	1.26	2.5
007	771008	31	13.7	110	276	2.0	0.09	0.005	1.28	2.5
008	771008	02	13.0	109	274	2.6	0.07	0.003	1.05	2.0
008	771008	11	13.0	109	273	3.3	0.07	0.002	1.08	2.0
009	771008	02	13.5	109	276	1.0	0.10	0.004	1.33	2.5
009	771008	31	13.7	110	276	1.5	0.10	0.003	1.30	2.5
010	771005	02	14.0	110	278	0.7	0.07	0.003	1.03	3.0
010	771005	28	14.0	111	278	0.8	0.08	0.005	1.08	3.0
011	771005	02	14.0	109	278	1.2	0.06	0.001	1.10	2.5
011	771005	13	14.0	106	277	1.3	0.06	0.001	1.09	2.5
012	771005	02	14.0	107	273	1.0	0.04	0.002	1.45	2.0
012	771005	07	14.0	108	273	1.0	0.04	0.002	1.46	2.0
013	771005	02	14.5	109	276	1.3	0.05	0.002	1.39	2.5
013	771005	13	14.5	106	274	1.2	0.06	0.002	1.51	2.5
014	771005	02	14.5	109	280	1.5	0.07	0.009	1.05	2.0
014	771005	17	14.5	109	280	1.7	0.07	0.009	1.06	2.0
015	771005	02	14.5	110	281	1.3	0.06	0.010	0.92	2.0
015	771005	20	14.5	111	280	2.2	0.06	0.012	0.93	2.0
016	771005	02	14.5	107	284	2.2	0.01	0.005	0.50	2.0
016	771005	16	14.5	111	283	2.6	0.01	0.005	0.50	2.0
017	771008	02	12.4	111	277	2.1	0.02	0.004	0.43	-.-
017	771008	08	13.0	112	277	2.8	0.01	0.004	0.42	-.-
018	771006	02	13.0	109	276	0.9	0.10	0.002	1.23	4.0
018	771006	18	13.5	112	276	2.0	0.10	0.002	1.25	4.0
019	771006	02	13.5	109	275	1.0	0.12	0.004	1.10	4.0
019	771006	31	13.8	110	274	1.0	0.12	0.004	1.04	4.0
020	771006	02	14.0	108	270	0.7	0.13	0.002	0.63	4.0
020	771006	42	10.5	108	273	0.8	0.18	0.002	1.05	4.0
021	771006	02	14.0	109	272	0.8	0.12	0.001	1.04	4.0
021	771006	22	14.0	109	272	0.9	0.12	0 001	1.01	4.0
022	771006	02	13.2	109	272	0.8	0.12	0.001	1.10	4.0
022	771006	25	08.5	109	275	0.8	0.23	0.001	1.42	4.0
023	771006	02	14.0	109	272	0.8	0.13	0.003	0.88	-.-
023	771006	21	14.0	108	273	0.8	0.13	0.003	1.02	-.-
024	771006	02	13.0	106	275	1.2	0.07	0.005	1.40	3.0
024	771006	15	13.2	107	272	1.0	0.07	0.006	1.41	3.0
025	771006	02	13.0	107	271	1.5	0.05	0.003	1.43	2.0
025	771006	07	12.5	107	271	1.7	0.05	0.003	1.43	2.0

APPENDIX B. Summary of phytoplankton species occurrence in the near-surface waters of Green Bay during 1977 sampling season. Summary is based on all samples analyzed. Summary includes the total number of samples in which a given taxon was noted, the average population density (cells/ml), the average relative abundance (% of assemblage), the maximum population density encountered (cells/ml), and the maximum relative abundance (% of assemblage) encountered.

	#	Average		Maximum	
	slides	cells/ml	% pop	cells/ml	% pop
CYANOPHYTA					
Agmenellum quadruplicatum (Menegh.) Bréb.	56	32.421	0.482	546.637	7.284
Anabaena flos-aquae (Lyngb.) Bréb.	55	79.402	1.125	1746.724	19.524
A. subcylindrica Borge	13	2.061	0.027	98.436	1.336
Anacystis cyanea (Kütz.) Dr. & Daily	38	124.423	1.767	2775.072	23.993
A. incerta (Lemm.) Dr. & Daily	102	1367.213	21.983	7567.043	77.087
A. thermalis (Menegh.) Dr. & Daily	96	68.474	1.132	291.121	4.318
Chroococcus dispersus var. *minor* G. M. Smith	94	862.543	12.456	5430.762	54.377
Chroococcus sp.	1	0.034	0.000	4.189	0.044
Gomphosphaeria aponina Kütz.	31	0.687	0.012	8.378	0.167
G. lacustris Chod.	86	6.029	0.109	27.227	0.552
G. wichurae (Hilse) Dr. & Daily	17	0.419	0.007	6.283	0.104
Microcoleus lyngbyaceus Kütz.	2	0.034	0.000	2.094	0.024
Microcoleus sp.	1	0.017	0.000	2.094	0.024
Oscillatoria bornetii Zukal	15	2.078	0.038	159.174	1.670
O. retzii Ag.	37	5.596	0.109	165.457	2.982
O. tenuis Ag.	1	0.017	0.001	2.094	0.070
Schizothrix calcicola (Ag.) Gom.	19	6.752	0.085	238.761	2.704
Schizothrix spp.	2	0.034	0.001	2.094	0.072
Total for Division (18 species)		2558.231	39.335		
CHLOROPHYTA					
Actinastrum hantzschii Lag.	1	0.117	0.001	14.661	0.155
Actinastrum spp.	1	0.117	0.002	14.661	0.195
Ankistrodesmus braunii (Näg.) Brunnthaler	94	11.310	0.211	50.265	0.969
A. gracilis (Reinsch) Korš.	3	0.101	0.005	6.283	0.410
A. nannoselene Skuja	50	2.631	0.046	23.038	0.424
Ankistrodesmus spp.	7	0.168	0.003	4.189	0.059
Ankistrodesmus stipitatus (Chod.) Kom.-Leg.	10	8.411	0.421	362.330	12.673
Asterococcus sp.	1	0.017	0.000	2.094	0.021
Closteriopsis acicularis (G. M. Smith) Belcher et. Swale	28	1.056	0.019	12.566	0.252
C. longissima Lemm.	18	0.519	0.011	8.378	0.189
Closteriopsis sp.	2	0.034	0.000	2.094	0.037
Coelastrum cambricum Archer	2	0.402	0.008	33.510	0.703
C. microporum Näg.	13	3.552	0.068	67.021	1.468
Coelastrum spp.	2	0.419	0.006	35.605	0.485

(continued)

APPENDIX B (continued).

	# slides	Average cells/ml	Average % pop	Maximum cells/ml	Maximum % pop
Cosmarium angulosum Bréb.	33	0.871	0.016	14.661	0.149
C. geometricum var. *suecicum* Borge	10	0.352	0.007	12.566	0.265
C. moniliforme (Turp.) Ralfs	18	0.352	0.005	6.283	0.088
Cosmarium spp.	8	0.151	0.003	4.189	0.071
Crucigenia quadrata Morren	10	0.821	0.014	16.755	0.362
Dictyosphaerium ehrenbergianum Näg.	41	10.271	0.184	106.814	1.656
Dictyosphaerium spp.	2	0.402	0.010	33.510	0.766
Elakatothrix gelatinosa Wille	16	0.637	0.012	10.472	0.179
Franceia ovalis (Francé) Lemm.	3	0.101	0.002	4.189	0.102
Gloeocystis planctonica (West & West)	116	235.107	3.717	1750.913	23.048
Gloeocystis sp.	62	6.702	0.120	190.590	3.689
Gloeocystis spp.	1	0.034	0.000	4.189	0.061
Golenkinia radiata (Chod.) Wille	6	0.352	0.005	23.038	1.178
Kirchneriella contorta (Schmidle) Bohlin	9	0.402	0.007	25.133	0.297
K. obesa (W. West) Schmidle	18	2.631	0.039	83.776	1.141
Kirchneriella sp.	12	0.251	0.004	4.189	0.076
Kirchneriella spp.	4	0.101	0.003	4.189	0.146
Lagerheimia citriformis (Snow) G. M. Smith	32	0.955	0.018	14.661	0.264
L. subsalsa Lemm.	3	0.050	0.001	2.094	0.053
Micractinium spp.	2	0.034	0.001	2.094	0.067
Monoraphidium contortum (Thuret ex Bréb.) Kom. -Leg.	32	0.905	0.021	16.755	0.363
M. setiforme (Näg.) Kom. - Leg.	26	18.230	0.952	594.808	23.203
Monoraphidium spp.	2	0.134	0.003	8.378	0.194
Monoraphidium tortile (West et West) Kom. - Leg.	26	1.642	0.056	39.793	1.914
Mougeotia sp.	19	5.479	0.080	117.286	1.948
Mougeotia spp.	11	0.938	0.017	27.227	0.463
Nephrocytium agardhianum Näg.	20	1.257	0.019	25.133	0.438
Nephrocytium sp.	9	0.436	0.009	16.755	0.226
Nephrocytium spp.	1	0.017	0.000	2.094	0.031
Oocystis parva West & West	38	29.556	0.510	345.575	5.753
Oocystis sp.	9	9.400	0.153	198.967	3.919
Oocystis spp.	107	133.785	2.384	563.392	12.889
Pediastrum biradiatum Meyen	2	0.804	0.023	67.021	2.379
P. boryanum (Turp.) Menegh.	48	20.961	0.353	201.062	2.930
P. duplex Meyen	8	2.128	0.038	60.737	1.216
P. duplex var. *rugulosum* Racib.	3	0.905	0.022	39.793	1.540
P. duplex var. *reticulatum* Lag.	1	0.268	0.004	33.510	0.488
P. obtusum Lucks	2	0.536	0.005	58.643	0.501

(continued)

APPENDIX B (continued).

	# slides	Average cells/ml	Average % pop	Maximum cells/ml	Maximum % pop
Pediastrum simplex var. *duodenarium* (Bailey) Rabh.	8	1.642	0.024	62.832	0.978
P. simplex (Meyen) Lemm.	4	0.922	0.016	64.926	0.974
Pediastrum spp.	1	0.067	0.005	8.378	0.602
Pediastrum tetras (Ehr.) Ralfs.	11	2.781	0.039	94.248	1.119
Pedinomonas minuta Skuja	99	60.971	1.354	1086.990	17.418
Quadrigula closterioides (Bohlin) Printz	2	0.469	0.008	33.510	0.527
Q. lacustris (Chod.) G. M. Smith	1	0.168	0.002	20.944	0.294
Quadrigula spp.	1	0.017	0.000	2.094	0.035
Scenedesmus acuminatus (Lag.) Chod.	17	1.676	0.028	37.699	0.571
S. armatus (Chod.) G. M. Smith	1	0.067	0.003	8.378	0.324
S. armatus var. *boglariensis* Hortob.	1	0.268	0.004	33.510	0.491
S. bicaudatus (Hansg.) Chod.	45	5.395	0.093	50.265	1.350
S. bijuga (Turp.) Lag.	10	0.905	0.019	25.133	0.892
S. denticulatus var. *linearis* Hansg.	102	37.095	0.627	247.138	2.360
S. ecornis var. *disciformis* Chod.	2	0.201	0.003	16.755	0.277
S. intermedius Chod.	1	0.067	0.001	8.378	0.130
S. minutus (G. M. Smith) Chod.	39	4.524	0.090	46.[illegible]77	1.447
S. quadricauda (Turp.) Bréb.	89	24.395	0.423	148.702	3.156
S. serratus (Corda) Bohlin	13	1.313	0.019	32.221	0.402
Scenedesmus sp.	2	0.050	0.001	4.189	0.081
Scenedesmus spinosus Chod.	34	3.820	0.056	75.398	0.614
Scenedesmus spp.	6	0.201	0.014	6.283	0.478
Staurastrum cuspidatum (Bréb.)	1	0.017	0.000	2.094	0.039
S. dejectum var. *inflatum* W. West	6	0.101	0.002	2.094	0.059
S. paradoxum Meyen	32	0.720	0.014	6.283	0.170
Staurastrum spp.	8	0.285	0.004	16.755	0.133
Tetraedron hastatum (Reinsch) Hansg.	4	0.101	0.001	6.283	0.062
T. minimum (A. Braun) Hansg.	66	3.583	0.052	125.664	1.074
Tetraedron sp.	1	0.017	0.000	2.094	0.028
Tetraedron spp.	3	0.050	0.001	2.094	0.071
Tetraedron trigonum (Näg.) Hansg.	1	0.017	0.000	2.094	0.033
Tetrastrum staurogeniaeforme (Schroeder) Lemm.	1	0.067	0.001	8.378	0.065
Ulothrix subtilissima (Rabh.)	48	16.336	0.302	146.608	3.945
Undetermined green individual	70	7.420	0.166	96.342	2.211
Total for Division (86 species)		692.525	12.986		

(continued)

APPENDIX B (continued).

	# slides	Average		Maximum	
		cells/ml	% pop	cells/ml	% pop
BACILLARIOPHYTA					
Achnanthes affinis Grun.	12	0.318	0.008	10.472	0.242
A. biasolettiana (Kütz.) Grun.	6	0.268	0.008	23.038	0.627
A. bioreti Germain	2	0.034	0.001	2.094	0.074
A. clevei Grun.	9	0.251	0.005	6.283	0.223
A. clevei var. *rostrata* Hust.	39	1.388	0.036	20.944	0.609
A. deflexa Reim.	7	0.318	0.016	20.944	1.208
A. exigua Grun.	8	0.251	0.007	8.378	0.324
A. lanceolata (Bréb.) Grun.	7	0.151	0.005	4.189	0.225
A. lanceolata var. *dubia* Grun.	4	0.067	0.002	2.094	0.146
A. lapponica (Hust.) Hust.	18	0.754	0.041	23.038	1.329
A. lauenburgiana Hust.	2	0.034	0.001	2.094	0.065
A. levanderi Hust.	1	0.017	0.001	2.094	0.146
A. linearis (Wm. Smith) Grun	3	0.050	0.001	2.094	0.033
A. microcephala (Kütz.) Grun.	41	3.368	0.168	92.094	5.314
A. minutissima Kütz.	33	1.776	0.033	25.133	0.486
A. peragalli Brun. et Herib.	1	0.017	0.000	2.094	0.026
A. pinnata Hust.	15	0.318	0.010	8.378	0.205
A. ploenensis Hust.	1	0.017	0.000	2.094	0.042
Achnanthes spp.	9	0.486	0.013	37.699	0.707
Amphipleura pellucida Kütz.	71	12.039	0.206	104.720	1.440
Amphora calumetica (Thomas ex Wolle) M. Perig.	1	0.034	0.001	4.189	0.069
A. hemicycla Stoerm.	1	0.017	0.000	2.094	0.045
A. ovalis var. *affinis* (Kütz.) V. H.	4	0.117	0.003	6.283	0.203
A. ovalis var. *pediculus* (Kütz.) V. H.	11	0.620	0.007	52.360	0.520
A. perpusilla Grun.	72	5.036	0.147	75.398	1.208
Amphora spp.	6	0.117	0.003	4.189	0.101
Amphora veneta var. *capitata* Haworth	2	0.034	0.001	2.094	0.146
Asterionella formosa Hass.	110	82.348	1.590	320.442	7.950
Attheya zachariasi Brun.	1	0.017	0.001	2.094	0.074
Caloneis bacillaris var. *thermalis* (Grun.) A. Cl.	2	0.050	0.002	4.189	0.203
C. bacillum (Grun.) Cl.	3	0.050	0.001	2.094	0.102
Cocconeis diminuta Pant.	7	0.117	0.004	2.094	0.151
C. pediculus Ehr.	3	0.101	0.002	6.283	0.162
C. placentula var. *euglypta* (Ehr.) Cl.	1	0.034	0.000	4.189	0.059
C. placentula var. *lineata* (Ehr.) V. H.	27	0.670	0.024	8.378	0.437
C. placentula Ehr.	1	0.034	0.001	4.189	0.162
Cocconeis sp. #2	20	0.737	0.017	10.472	0.405

(continued)

APPENDIX B (continued).

	# slides	Average cells/ml	Average % pop	Maximum cells/ml	Maximum % pop
Cyclotella atomus Hust.	2	0.034	0.001	2.094	0.121
C. comensis Grun.	115	292.252	4.822	5338.609	42.342
C. comta (Ehr.) Kütz.	109	17.875	0.358	112.775	2.350
C. kutzingiana Thw.	1	0.017	0.000	2.094	0.045
C. meneghiniana Kütz.	20	0.617	0.010	10.472	0.223
C. meneghiniana var. *plana* Fricke	11	0.352	0.008	6.283	0.176
C. michiganiana Skv.	1	0.017	0.000	2.094	0.046
C. ocellata Pant.	4	0.101	0.005	6.283	0.277
C. pseudostelligera Hust.	17	1.642	0.032	48.171	0.967
Cyclotella spp.	4	0.151	0.003	8.378	0.201
Cyclotella stelligera (Cl. et Grun.) V. H.	65	12.164	0.399	263.894	11.634
Cymatopleura solea (Breb. et Godey) Wm. Smith	9	0.201	0.010	4.189	0.813
Cymatopleura sp.	1	0.017	0.000	2.094	0.033
Cymbella affinis Kütz.	2	0.067	0.004	4.189	0.292
C. cistula (Ehr.) Kirchn.	2	0.034	0.001	2.094	0.046
C. delicatula Kütz.	1	0.017	0.001	2.094	0.070
C. hustedtii Krasske	2	0.034	0.001	2.094	0.081
C. laevis Näg.	1	0.017	0.000	2.094	0.046
C. microcephala Grun.	51	2.932	0.083	37.699	1.626
C. minuta Hilse	21	0.519	0.028	6.283	0.813
C. norvegica Grun.	2	0.034	0.000	2.094	0.029
C. parvula Krasske	4	0.084	0.004	4.189	0.242
C. prostrata var. *auerswaldii* (Rabh.) Reim.	5	0.117	0.006	4.189	0.292
C. prostrata (Berk.) Cl.	1	0.017	0.000	2.094	0.026
C. proxima Reim.	1	0.017	0.001	2.094	0.081
C. sinuata Greg.	2	0.034	0.001	2.094	0.169
Cymbella sp. #22	2	0.084	0.002	6.283	0.118
Cymbella sp.	1	0.017	0.000	2.094	0.021
Cymbella spp.	6	0.101	0.002	2.094	0.102
Cymbella subaequalis Grun.	1	0.017	0.000	2.094	0.031
Cymbella tumida (Bréb. et Kütz.) V. H.	1	0.017	0.000	2.094	0.027
Denticula tenuis var. *crassula* (Näg. ex Kütz.) Hust.	18	0.586	0.011	14.661	0.302
D. tenuis Kütz.	1	0.050	0.001	6.283	0.118
Diatoma ehrenbergii Kütz.	3	0.955	0.020	71.209	1.402
Diatoma spp.	1	0.017	0.001	2.094	0.081
Diatoma tenue Ag.	30	4.318	0.403	238.761	15.756
Diatoma tenue var. *elongatum* Lyngb.	20	0.503	0.012	8.378	0.434
D. tenue var. *pachycephala* Grun.	1	0.017	0.001	2.094	0.101
Diploneis oculata (Bréb.) Cl.	1	0.017	0.001	2.094	0.070

(continued)

APPENDIX B (continued).

	# slides	Average		Maximum	
		cells/ml	% pop	cells/ml	% pop
Diploneis ovalis (Hilse et Rabh.) Cl.	1	0.017	0.000	2.094	0.031
D. parma Cl.	1	0.017	0.001	2.094	0.102
Diploneis spp.	2	0.034	0.001	2.094	0.070
Entomoneis ornata (Bailey) Reim.	11	0.285	0.006	8.378	0.297
Epithemia spp.	1	0.050	0.001	6.283	0.086
Fragilaria brevistriata Grun. ex V. H.	9	0.586	0.015	16.755	0.704
F. brevistriata var. *inflata* (Pant.) Hust.	12	0.436	0.020	8.378	0.758
F. capucina Desm.	72	90.394	1.561	1514.407	27.364
F. capucina var. *mesolepta* (Rabh.) Rabh.	3	0.201	0.005	12.566	0.352
F. construens (Ehr.) Grun.	27	3.302	0.066	108.903	1.802
F. construens var. *binodis* (Ehr.) Grun.	3	0.134	0.003	12.566	0.232
F. construens var. *capitata* Hérib.	1	0.034	0.000	4.189	0.059
F. construens var. *minuta* Temp. et Per.	18	0.871	0.030	18.850	0.965
F. construens var. *pumila* Grun.	5	1.102	0.012	64.443	0.671
F. construens var. *subsalina* Hust.	9	0.855	0.036	43.982	2.113
F. construens var. *venter* (Ehr.) Grun.	8	0.771	0.011	41.888	0.323
F. crotonensis Kitton	113	128.207	3.372	1159.972	18.652
F. intermedia Grun.	7	0.402	0.028	20.944	2.421
F. intermedia var. *fallax* (Grun.) A. Cl.	3	0.148	0.002	8.055	0.107
F. lapponica Grun.	3	0.182	0.004	8.378	0.319
F. leptostauron (Ehr.) Hust.	3	0.067	0.002	4.189	0.101
F. pinnata var. *lancettula* (Schum.) Hust.	4	0.302	0.006	29.322	0.584
F. pinnata Ehr.	72	15.980	0.347	186.401	3.711
Fragilaria spp.	14	0.989	0.061	25.133	3.183
Fragilaria vaucheriae (Kütz.) Peters.	11	0.436	0.029	14.661	2.251
F. vaucheriae var. *capitellata* (Grun.) Patr.	26	2.815	0.141	111.003	11.910
F. vaucheriae var. *lanceolata* A. Mayer	1	0.134	0.001	16.755	0.143
Frustulia weinholdii Hust.	1	0.017	0.001	2.094	0.074
Gomphonema angustatum (Kütz.) Rabh.	6	0.101	0.002	2.094	0.059
G. gracile Ehr.	1	0.017	0.001	2.094	0.081
G. intricatum var. *dichotomum* (Kütz.) Grun. ex V. H.	15	0.402	0.014	8.378	0.322
G. olivaceum (Lyngb.) Kütz.	6	0.101	0.004	2.094	0.181
G. parvulum (Kütz.) Kütz.	3	0.050	0.001	2.094	0.081
G. quadripuncatum (Öst.) Wis.	1	0.034	0.001	4.189	0.076
Gomphonema spp.	2	0.034	0.001	2.094	0.074
Gyrosigma acuminatum (Kütz.) Rabh.	3	0.050	0.001	2.094	0.029
G. scalproides (Rabh.) Cl.	1	0.017	0.000	2.094	0.039
Melosira distans (Ehr.) Kütz.	1	0.017	0.000	2.094	0.033

(continued)

APPENDIX B (continued).

	# slides	Average		Maximum	
		cells/ml	% pop	cells/ml	% pop
Melosira granulata alpha status (Ehr.) Ralfs	3	0.553	0.006	35.605	0.326
M. granulata var. *angustissima* O. Müll.	10	0.452	0.011	12.566	0.243
M. granulata (Ehr.) Ralfs	60	14.430	0.295	268.082	6.240
M. islandica O. Müll.	27	4.139	0.361	56.549	10.976
M. italica subsp. *subarctica* O. Müll.	64	5.859	0.331	64.926	5.263
M. varians Ag.	1	0.017	0.000	2.094	0.027
Navicula acceptata Hust.	1	0.017	0.000	2.094	0.039
N. anglica var. *signata* Hust.	2	0.050	0.003	4.189	0.242
N. anglica var. *subsalsa* (Grun.) Cl.	2	0.034	0.000	2.094	0.018
N. aurora Sov.	1	0.017	0.000	2.094	0.033
N. bryophila Peters.	2	0.034	0.002	2.094	0.102
N. capitata (Ehr.)	2	0.034	0.001	2.094	0.081
N. capitata var. *hungarica* (Grun.) Ross	2	0.050	0.001	4.189	0.149
N. capitata var. *luneburgensis* (Grun.) Patr.	12	0.366	0.012	8.055	0.407
N. cocconeiformis Greg. <u>ex</u> Grev.	2	0.034	0.001	2.094	0.151
N. constans var. *symmetrica* Hust.	1	0.067	0.001	8.378	0.168
N. cryptocephala var. *intermedia* Grun.	15	0.385	0.012	8.378	0.305
N. cryptocephala var. *veneta* (Kütz.) Rabh.	27	0.768	0.017	10.472	0.405
N. cryptocephala Kütz.	18	0.534	0.013	8.055	0.322
N. decussis Østr.	3	0.067	0.003	4.189	0.203
N. exigua (Greg.) Grun. V. H.	1	0.050	0.002	6.283	0.223
N. exiguiformis Hust.	4	0.067	0.001	2.094	0.081
N. explanata Hust.	4	0.115	0.004	8.055	0.239
N. gottlandica Grun.	3	0.050	0.001	2.094	0.074
N. gregaria Donk.	6	0.251	0.010	18.850	1.087
N. jaernefeltii Hust.	1	0.017	0.000	2.094	0.026
N. lanceolata (Ag.) Kütz.	5	0.084	0.001	2.094	0.081
N. latens Krasske	1	0.017	0.001	2.094	0.081
N. luzonensis Hust.	16	0.503	0.011	10.472	0.301
N. menisculus Schum.	4	0.115	0.001	8.055	0.084
N. menisculus var. *obtusa* Hust.	7	0.134	0.003	4.189	0.084
N. menisculus var. *upsaliensis* Grun.	1	0.017	0.000	2.094	0.031
N. minima Grun. <u>ex</u> V. H.	4	0.184	0.006	10.472	0.405
N. paludosa Hust.	4	0.067	0.002	2.094	0.101
N. placentula var. *rostrata* Mayer	1	0.017	0.001	2.094	0.151
N. protracta (Grun. <u>in</u> Cl. <u>et</u> Grun.) Cl.	1	0.017	0.001	2.094	0.151
N. pupula Kütz.	8	0.184	0.005	6.283	0.162
N. pupula var. *mutata* (Krasske) Hust.	1	0.017	0.001	2.094	0.074

(continued)

APPENDIX B (continued).

	# slides	Average cells/ml	Average % pop	Maximum cells/ml	Maximum % pop
Navicula pupula var. *rectangularis* (Greg.) Grun.	1	0.017	0.001	2.094	0.074
N. radiosa var. *parva* Wallace	6	0.134	0.007	4.189	0.242
N. radiosa var. *tenella* (Bréb.) Grun.	38	1.089	0.042	10.472	1.626
N. radiosa Kütz.	2	0.034	0.000	2.094	0.041
N. rhynchocephala Kütz.	4	0.084	0.005	4.189	0.478
N. rhynchocephala var. *germanii* (Wallace) Patr.	1	0.017	0.002	2.094	0.239
N. scutelloides Wm. Smith	1	0.017	0.001	2.094	0.074
N. seminuloides Hust.	17	0.536	0.013	12.566	0.487
N. seminulum Grun.	1	0.017	0.001	2.094	0.070
N. similis Krasske	1	0.017	0.001	2.094	0.106
Navicula sp. #8	4	0.067	0.003	2.094	0.121
Navicula sp.	1	0.034	0.001	4.189	0.074
Navicula splendicula Van Landingham	1	0.017	0.000	2.094	0.018
Navicula spp.	36	1.608	0.068	31.416	1.220
Navicula stroemii Hust.	1	0.017	0.000	2.094	0.021
N. stroesei A. Cl.	3	0.050	0.002	2.094	0.121
N. subrotundata Hust.	5	0.101	0.004	4.189	0.301
N. subtilissima Cl.	1	0.017	0.001	2.094	0.066
N. tantula Hust.	9	0.151	0.004	2.094	1.146
N. tripunctata (O. F. Müll.) Bory	4	0.067	0.002	2.094	0.102
N. tuscula fo. *minor* Hust.	4	0.067	0.001	2.094	0.065
N. tuscula fo. *rostrata* Hust.	1	0.017	0.002	2.094	0.205
N. viridula var. *avenacea* (Bréb. ex Grun.) V. H.	1	0.017	0.001	2.094	0.102
N. zanoni Hust.	6	0.101	0.002	2.094	0.067
Neidium dubium fo. *constrictum* Hust.	1	0.017	0.001	2.094	0.074
Neidium sp.	1	0.017	0.000	2.094	0.021
Nitzschia acicularioides Arch.	66	7.104	0.160	73.304	3.659
N. acicularis (Kütz.) Wm. Smith	11	0.452	0.006	31.416	0.249
N. acuta Hantz.	3	0.050	0.001	2.094	0.036
N. adapta Hust.	15	0.570	0.011	14.661	0.372
N. amphibia Grun.	2	0.067	0.001	6.283	0.062
N. angustata (Wm. Smith) Grun. in Cl. and Grun.	1	0.017	0.000	2.094	0.018
N. angustata var. *acuta* Grun.	1	0.017	0.000	2.094	0.029
N. apiculata (Greg.) Grun.	2	0.034	0.001	2.094	0.101
N. capitellata Hust.	3	0.050	0.001	2.094	0.081
N. confinis Hust.	3	0.050	0.002	2.094	0.145
N. dissipata (Kütz.) Grun.	11	0.218	0.008	6.283	0.407
N. fonticola Grun.	35	1.860	0.032	31.416	0.573
N. frustulum var. *tenella* Grun. ex V. H.	3	0.067	0.001	4.189	0.092

(continued)

APPENDIX B (continued).

	#	Average		Maximum	
	slides	cells/ml	% pop	cells/ml	% pop
Nitzschia gracilis Hantz.	36	1.474	0.049	14.661	1.626
N. hantzschiana Rabh.	3	0.050	0.001	2.094	0.074
N. holsatica Hust.	16	6.600	0.097	161.107	1.826
N. hungarica Grun.	1	0.017	0.001	2.094	0.074
N. intermedia Hantz. <u>ex</u> Cl. <u>et</u> Grun.	1	0.034	0.001	4.189	0.085
N. kutzingiana Hilse	1	0.017	0.000	2.094	0.031
N. lauenbergiana Hust.	16	0.414	0.013	16.111	0.410
N. linearis Wm. Smith	5	0.117	0.002	6.283	0.137
N. microcephala Grun.	1	0.017	0.000	2.094	0.022
N. palea (Kütz.) Wm. Smith	56	2.513	0.080	27.227	1.608
N. palea var. *tenuirostris* Hust.	2	0.084	0.002	6.283	0.117
N. parvula Wm. Smith	1	0.017	0.001	2.094	0.074
N. recta Hantz.	6	0.134	0.005	6.283	0.202
N. romana Grun.	16	0.804	0.016	18.850	0.324
N. sigma (Kütz.) Wm. Smith	1	0.017	0.001	2.094	0.070
N. sociabilis Hust.	9	0.218	0.009	4.189	0.478
Nitzschia sp.	8	0.567	0.009	29.322	0.291
Nitzschia spp.	48	1.994	0.073	14.661	2.033
Nitzschia subacicularis Hust.	16	0.385	0.011	6.283	0.242
N. subcapitellata Hust.	8	0.151	0.002	4.189	0.057
N. sublinearis Hust.	1	0.017	0.000	2.094	0.029
Opephora martyi Hérib.	3	0.084	0.001	4.189	0.061
Rhizosolenia eriensis H. L. Smith	52	4.370	0.139	90.059	6.223
R. gracilis H. L. Smith	37	3.561	0.105	46.077	3.039
Rhoicosphenia curvata (Kütz.) Grun.	3	0.101	0.003	6.283	0.153
Skeletonema potamos (Weber) Hasle	16	1.424	0.021	48.171	0.502
Skeletonema sp.	5	1.089	0.024	77.493	1.709
Skeletonema spp.	2	0.115	0.002	8.055	0.223
Stauroneis smithii var. *minima* Haworth	1	0.017	0.000	2.094	0.028
S. smithii Grun.	1	0.017	0.000	2.094	0.026
Stephanodiscus alpinus Hust.	13	0.402	0.012	10.472	0.363
S. binderanus (Kütz.) Krieger	26	3.998	0.068	72.498	1.042
S. dubius (Fricke) Hust.	2	0.034	0.001	2.094	0.092
S. hantzschii Grun.	59	14.600	0.283	196.873	3.859
S. minutus Grun.	84	24.312	0.673	159.174	20.159
S. niagarae Ehr.	103	38.732	0.822	358.141	12.714
Stephanodiscus sp. #10	1	0.017	0.000	2.094	0.039
Stephanodiscus sp. #14	3	0.838	0.027	77.493	2.998
Stephanodiscus sp. #8	69	21.651	0.414	326.725	8.023

(continued)

APPENDIX B (continued).

	# slides	Average cells/ml	Average % pop	Maximum cells/ml	Maximum % pop
Stephanodiscus sp. #9	1	0.017	0.000	2.094	0.040
Stephanodiscus sp.	1	0.050	0.001	6.283	0.071
Stephanodiscus spp.	3	0.184	0.003	18.850	0.275
Stephanodiscus subtilis (Van Goor) A. Cl.	41	8.260	0.537	464.955	49.888
S. tenuis Hust.	5	0.168	0.013	12.566	1.348
Surirella angusta Kütz.	3	0.050	0.002	2.094	0.121
S. ovata var. *pinnata* (Wm. Smith) Hust.	1	0.017	0.000	2.094	0.059
Synedra acus Kütz.	3	0.050	0.001	2.094	0.092
S. delicatissima Wm. Smith	1	0.017	0.000	2.094	0.028
S. delicatissima var. *angustissima* Grun.	30	1.254	0.083	14.661	2.033
S. filiformis var. *exilis* A. Cl.	6	0.134	0.005	4.189	0.225
S. filiformis Grun.	95	14.331	0.393	94.248	4.878
S. ostenfeldii (Krieger) A. Cl.	36	10.682	0.834	190.590	15.424
S. parasitica var. *subconstricta* (Grun.) Hust.	1	0.017	0.001	2.094	0.101
S. parasitica (Wm. Smith) Hust.	5	0.235	0.004	14.661	0.270
S. rumpens Kütz.	1	0.050	0.001	6.283	0.118
S. rumpens var. *fragilarioides* Grun. ex V. H.	2	0.117	0.008	8.378	0.583
Synedra sp. #17	1	0.017	0.000	2.094	0.036
Synedra spp.	11	0.369	0.025	14.661	0.788
Synedra ulna var. *chaseana* Thomas	2	0.050	0.001	4.189	0.162
S. ulna (Nitz.) Ehr.	10	0.249	0.013	8.055	0.407
Tabellaria fenestrata (Lyngb.) Kütz.	85	22.280	0.371	341.386	5.005
T. flocculosa (Roth) Kütz.	1	0.101	0.002	12.566	0.255
T. flocculosa var. *linearis* Koppen	106	38.048	0.919	426.934	6.935
Thalassiosira fluviatilis Hust.	1	0.017	0.000	2.094	0.016
Total for Division (255 species)		970.121	22.084		
CHRYSOPHYTA					
Chrysococcus sp.	1	0.084	0.001	10.472	0.142
Chrysophycean cyst	1	0.017	0.000	2.094	0.031
Chrysosphaerella longispina Lautb.	39	6.532	0.102	117.286	1.945
Dinobryon cyst	92	12.213	0.552	83.776	9.569
D. cysts	1	0.335	0.004	41.888	0.444
D. divergens Imhof	46	10.422	0.183	154.985	4.924
Dinobryon sp.	2	0.117	0.005	12.566	0.420
Dinobryon spp.	18	4.960	0.263	115.192	8.669
Dinobryon stokesii var. *epiplancticum* Skuja	24	2.178	0.031	41.888	0.548
Mallomonas alpina Pasch. et Ruttn.	52	2.312	0.043	18.850	0.502

(continued)

APPENDIX B (continued).

	# slides	Average cells/ml	Average % pop	Maximum cells/ml	Maximum % pop
Mallomonas pseudocoronata Presc.	48	1.642	0.025	23.038	0.242
Mallomonas sp.	3	0.067	0.001	4.189	0.045
Mallomonas spp.	12	0.486	0.020	14.661	1.020
Monochrysis aphanaster Skuja	96	5.529	0.130	25.133	1.746
Ochromonas sp. #3	71	48.405	0.709	869.173	11.793
Ochromonas sp. #4	47	9.517	0.514	98.436	9.631
Ochromonas spp.	5	44.368	0.533	1658.760	18.754
Ochromonas vallesiaca Chod.	90	55.509	1.310	691.150	9.234
Synura spp.	2	0.034	0.001	2.094	0.042
Synura uvella Ehr.	9	2.011	0.031	142.419	2.205
Total for Division (20 species)		206.736	4.459		
CRYPTOPHYTA					
Chroomonas spp.	118	58.862	1.530	368.613	11.149
Cryptomonas erosa Ehr.	1	0.134	0.002	16.755	0.295
C. gracilis Skuja	35	1.726	0.037	20.944	0.661
C. marssonii Skuja	120	40.166	0.876	196.873	5.584
C. ovata Ehr.	123	74.814	1.668	345.575	6.603
Rhodomonas minuta Skuja	122	380.017	9.151	3579.319	47.393
Total for Division (6 species)		555.719	13.265		
PYRROPHYTA					
Ceratium hirundinella (O. F. Müll.) Schrank	36	0.871	0.014	10.472	0.142
Gymnodinium helveticum Penard	20	0.670	0.017	12.566	0.428
Gymnodinium spp.	90	7.439	0.235	48.171	2.590
Peridinium spp.	57	2.458	0.086	20.944	1.844
Total for Division (4 species)		11.439	0.352		
EUGLENOPHYTA					
Phacus sp.	2	0.050	0.001	4.189	0.044
Trachelomonas sp.	1	0.017	0.000	2.094	0.021
Total for Division (2 species)		0.067	0.001		

(continued)

APPENDIX B (continued).

	# slides	Average cells/ml	Average % pop	Maximum cells/ml	Maximum % pop
HAPTOPHYTA					
Undetermined haptophyte sp. #1	56	28.867	0.485	475.427	14.424
Undetermined haptophyte sp. #2	33	1.223	0.018	20.944	0.391
Total for Division (2 species)		30.090	0.503		
UNDETERMINED					
Undetermined flagellate sp. #3	3	0.218	0.017	14.661	1.857
Undetermined flagellate sp. #5	25	2.295	0.048	56.549	1.744
Undetermined flagellate sp. #6	39	2.078	0.059	35.605	1.065
Undetermined flagellate sp. #7	9	0.302	0.004	8.378	0.108
Undetermined flagellate sp. #8	89	21.396	0.373	178.023	3.866
Undetermined flagellate sp. #9	48	6.618	0.109	90.059	1.186
Undetermined flagellate spp.	123	234.773	6.402	934.099	33.666
Total for Division (7 species)		267.680	7.013		

APPENDIX C. Phytoplankton density and species diversity of Green Bay, 1977. It includes total densities and Shannon-Weaver diversity (1963) for samples from May, August and October and densities and S/N diversity of May diatoms.

Location	Total Density (cells/ml)						Species Diversity						May Diatoms	
	Surface			Bottom			Surface			Bottom			(cells/ml)	S/N
	May*	August	October	May	August	October	May*	August	October	May	August	October		
1	651.4	5663.2	2584.5	-.-	3168.8	2817.0	2.166	2.510	3.355	-.-	3.027	3.424	278.6	0.089
2	2063.0	2817.0	6335.5	-.-	3566.8	7123.0	2.581	2.677	2.487	-.-	2.584	2.407	379.1	0.121
3	1734.2	4689.3	8794.4	-.-	4109.2	4570.0	3.319	2.581	2.090	-.-	2.752	2.847	1070.2	0.055
4	1436.8	5267.4	5885.2	-.-	3214.9	5022.4	3.065	2.604	2.368	-.-	2.626	2.916	368.6	0.106
5	875.5	5355.4	6863.3	-.-	4768.9	4565.8	2.631	2.605	2.501	-.-	2.638	2.889	56.5	0.301
6	1038.8	9012.2	9315.9	-.-	8871.9	6044.4	2.670	1.983	2.020	-.-	1.732	2.467	104.7	0.096
7	1235.7	8783.9	4308.2	-.-	1447.2	3920.7	2.948	2.105	2.354	-.-	2.995	2.579	628.3	0.038
8	-.-	7642.4	10067.8	-.-	6624.6	7342.9	-.-	2.003	2.441	-.-	2.373	2.582	515.2	0.058
9	789.6	10463.6	5078.9	-.-	2268.8	3103.9	2.584	1.930	2.361	-.-	2.403	2.764	360.2	0.028
10	1022.1	7518.9	5698.8	-.-	3675.7	6438.2	2.831	2.161	2.435	-.-	3.125	2.403	228.3	0.092
11	839.9	7370.2	6006.7	-.-	6857.0	7118.8	2.016	2.898	2.773	-.-	2.763	2.566	25.1	0.319
12	2081.8	8844.6	9873.0	-.-	7763.9	8048.8	2.480	2.656	2.827	-.-	2.959	2.990	393.7	0.089
13	1660.9	6821.4	4653.7	-.-	7810.0	4988.8	2.040	2.631	3.091	-.-	2.721	3.242	31.4	0.255
14	1966.6	8830.0	5682.1	-.-	2496.5	5024.4	2.172	2.737	2.903	-.-	2.821	2.893	67.0	0.239
15	1390.7	9433.1	6865.4	-.-	2919.6	4626.5	2.209	2.444	3.033	-.-	3.029	3.033	88.0	0.193
16	5166.9	9533.7	12962.2	-.-	5426.6	7504.2	1.887	2.629	2.971	-.-	2.722	3.340	56.5	0.053
17	-.-	2580.3	6423.5	-.-	2936.3	7921.0	-.-	3.039	3.192	-.-	2.856	2.910	932.0	0.018
18	7552.4	8924.2	3705.0	-.-	3256.8	6618.3	2.208	2.048	2.948	-.-	2.791	2.176	883.8	0.024
19	1105.8	10214.4	6264.3	-.-	2083.9	4046.4	2.562	1.980	1.827	-.-	3.334	2.614	337.2	0.053
20	1154.0	9271.9	4308.2	-.-	2268.2	3939.6	2.745	1.969	1.982	-.-	2.738	1.198	387.5	0.052
21	1154.0	6978.5	5076.8	-.-	2762.5	4934.4	2.682	2.092	2.073	-.-	2.887	2.329	374.9	0.048
22	865.0	5330.2	6354.4	-.-	5485.2	3568.8	2.677	2.363	1.545	-.-	2.483	1.266	301.6	0.050
23	1432.6	7328.3	5845.4	-.-	2168.5	3591.9	2.652	2.153	1.565	-.-	2.806	2.340	465.0	0.041
24	1859.8	7275.9	10206.0	-.-	7164.9	5434.9	2.546	2.456	1.778	-.-	2.529	2.502	584.3	0.039
25	2995.0	12608.3	11697.2	-.-	12608.3	7489.6	2.509	1.947	1.795	-.-	1.933	2.420	871.3	0.041

*May composite depth samples in contrast to discrete depth samples in August and October.

APPENDIX D. Euclidian distances (Sneath and Sokal, 1963) and cluster diagrams of the August and October phytoplankton assemblages.

Euclidian Distances, August

3	.34426										
4	.27711	.41469									
5	.44595	.32097	.20137								
2	.50543	.39026	.46497	.33526							
9	.95915	1.0107	1.0663	.80713	1.3647						
19	.58935	.49142	.54416	.50296	1.0423	.57375					
10	1.3102	1.2922	1.4247	1.2763	1.5923	.71336	1.0163				
18	1.2624	1.3763	1.3096	1.1777	1.5175	.77941	1.0522	.56141			
6	1.3332	1.3039	1.1073	.69156	1.4592	1.0548	.99550	1.8299	1.6961		
7	.80703	.75407	.57628	.33545	.91670	.68581	.50324	1.0646	1.0194	.26169	
20	1.0880	1.0728	.79483	.52549	1.1910	.88637	.71130	1.5864	1.3863	.15224	.11448
8	1.2803	1.5402	.94685	.76134	1.2046	.94845	1.2619	1.6736	1.3234	.61805	.51576
22	1.0519	1.1034	.63250	.37206	.72296	1.1991	1.1160	1.6783	1.4756	.44512	.34253
23	.57709	.82373	.32642	.38807	.70642	1.0390	.67321	1.5797	1.3592	.63099	.36192
24	1.0369	1.0019	.54534	.44680	.90660	1.2406	.94219	1.6593	1.4349	.95093	.57550
21	1.0824	.99291	.87929	.74625	1.1191	1.2006	.85143	1.7643	1.7001	.84960	.63771
25	3.1235	3.2901	2.6642	2.7773	3.3589	3.2333	2.8310	3.3389	3.3381	3.4741	2.9957
11	1.4884	1.5858	1.8221	1.7649	1.6808	1.7647	1.3472	1.1993	1.7074	2.8559	1.9647
12	1.4015	1.2907	1.8491	1.5366	1.6769	1.8014	1.2135	1.5340	1.6813	2.3908	1.6455
16	1.5297	1.1892	2.0334	1.7270	1.6162	1.8181	1.4103	1.6677	2.0456	2.6349	2.0913
13	2.6305	2.9566	2.8928	2.6577	2.8515	3.1081	2.7526	2.1817	2.2852	3.4758	2.5410
14	3.9314	3.6537	4.3037	3.9310	3.8310	3.8224	3.7261	2.7219	3.1053	4.5509	3.7682
15	3.6740	3.7057	4.1346	3.6003	3.6976	3.1617	3.6980	2.5725	2.8283	4.1918	3.4007
17	3.7068	3.5042	3.6077	3.4325	3.5017	4.3940	3.9055	2.7239	3.6626	4.5390	3.5903
Loc.	1	3	4	5	2	9	19	10	22	6	7

8	.46590										
22	.32865	.44474									
23	.30460	.51784	.32725								
24	.68622	.55459	.59746	.45906							
21	.63978	1.1478	.65182	.50919	.90897						
25	3.1592	2.9443	3.1811	2.6058	1.8071	2.5437					
11	2.6298	2.4717	2.5374	2.1617	1.9442	2.3238	3.9273				
12	2.1739	2.5923	2.4678	2.0280	2.0002	2.1639	3.9669	.91606			
16	2.6349	2.9313	2.8933	2.4085	2.4874	2.4757	4.2751	1.0282	.64075		
13	3.1914	3.5066	3.0087	2.9261	3.0560	3.1435	5.2470	2.0638	1.0253	2.3969	
14	4.3251	4.8174	4.5166	4.3425	4.3927	4.4680	6.4128	2.7963	1.9172	2.3130	2.0094
15	4.0425	4.1706	4.2896	4.1320	4.1112	4.1366	6.0668	2.7980	1.7206	2.0731	1.6547
17	4.3763	4.5062	3.9216	4.2610	4.1895	4.4307	5.7724	3.2650	2.9035	3.2073	3.1466
Loc.	20	8	22	23	24	21	25	11	12	16	13

15	1.0662	
17	3.7260	3.5363
Loc.	14	15

(continued)

APPENDIX D (continued).

Cluster Diagram, August

```
            2 2 2 2 2 1 1 1 1 1 1 1 1 1 1
            4 3 2 1 0 9 8 7 6 5 4 3 2 1 0 9 8 7 6 5 4 3 2 1
Loc.
   1      +---------I
   3      +---------I-I
   4      +---I       I-I-----------------------I
   5      +---I-------I I                       I
   2      +-------------I                       I-I
   9      +-----------------I                   I I
  19      +-----------------I---------------I   I I
  10      +-----------------------I         I---I I
  18      +-----------------------I---------I     I-----I
   6      +-----I                                 I     I-I
   7      +-I   I-------------------I             I     I I
  20      +-I---I                   I             I     I I
   8      +---------------I         I-I           I     I I
  22      +-------I       I---I     I I-----------I     I I
  23      +-------I-------I   I-----I I                 I I
  24      +-------------------I       I                 I I
  21      +---------------------------I                 I I
  25      +---------------------------------------------I I
  11      +-------------------------------I               I
  12      +---------------------I         I---------I     I
  16      +---------------------I---------I         I     I
  13      +-----------------------------------I     I-I---I
  14      +-----------------------------I     I-----I I
  15      +-----------------------------I-----I       I
  17      +-------------------------------------------I

        D   . . . . . . . . . . . . . . 1 1 1 2 2 3 3 4 4 1
        I   1 2 2 3 3 4 4 5 5 5 6 6 9 9 . . . . . . . . . 5
        S   1 0 3 2 4 5 7 3 7 8 4 6 5 9 0 0 1 0 8 6 9 3 8 .
        T   4 0 7 7 4 7 8 2 3 5 0 1 9 1 6 8 6 8 7 2 2 9 4 8
        A   4 3 8 2 2 0 0 6 7 0 7 4 3 7 6 2 3 7 8 2 9 4 5 2
        N   8 7 0 5 6 0 4 4 5 5 5 1 3 6 2 6 3 3 0 9 6 7 0 7
        C
        E
        S
```

(continued)

Euclidian Distances, October

10	1.9691										
11	2.0176	.74515									
13	1.7154	.72444	.42698								
14	1.5251	.84907	.85404	.45611							
15	1.5303	1.2600	1.0900	.77242	.41764						
17	1.9092	1.3449	1.2307	1.0215	.88533	.76618					
12	3.7712	1.3737	1.5393	1.6542	1.7740	2.0551	1.9726				
16	4.2786	3.7293	3.6751	3.1002	2.3937	2.5546	2.3403	2.7144			
2	1.4791	1.0719	.94592	1.0053	1.1932	1.7540	1.6500	2.4924	4.2238		
3	2.0291	1.2235	1.3855	1.3427	1.4948	2.1167	2.1368	2.4038	4.4688	.55225	
4	2.0354	1.5457	1.0937	1.0359	1.2553	1.9971	1.8637	2.1861	4.4442	.52350	.46872
6	2.7978	1.7193	1.9533	1.8495	2.4325	3.0324	2.9334	2.5244	5.2543	.97579	.57241
24	2.7507	2.1338	2.2523	1.8654	1.8310	2.8009	3.0036	2.6397	5.0047	1.3025	.92147
25	3.3454	3.3597	2.7545	2.6172	2.6077	3.5310	3.4821	3.3731	5.5809	1.8671	1.3994
8	4.9610	4.1611	3.4797	3.0729	3.8819	3.9343	4.3434	2.8534	6.6069	3.3216	2.6251
5	2.0797	2.1128	1.6608	1.4324	2.0674	2.4665	2.4627	2.8400	5.0145	.95819	.91178
22	1.6210	1.9362	1.9407	1.5706	1.7450	2.2407	2.4449	3.5639	5.2812	1.1135	1.2651
21	2.1568	1.4745	1.4676	1.0977	1.6199	2.1101	1.9756	3.0987	4.9537	.99332	.83946
7	1.4090	.99453	1.0118	.73673	1.1311	1.4331	1.6424	2.9348	4.5493	.98556	.93720
9	1.9746	.97324	.75805	.57351	1.0536	1.5425	1.7405	2.3077	4.4278	.93975	.82963
18	1.9456	1.1543	.70410	.63577	1.0311	1.4627	1.4669	1.9266	3.9896	.85668	1.3931
19	1.9813	1.6716	1.1462	1.5224	1.5593	2.1400	2.1348	2.6586	5.1447	.99873	.98019
23	1.5774	2.1219	1.8344	1.9269	1.9415	2.3666	2.5596	3.7422	5.7894	1.2875	1.3463
20	2.9454	2.7920	2.4856	2.4347	2.6639	3.0370	2.9025	4.4708	5.8238	1.7286	2.0449
Loc.	1	10	11	13	14	15	17	12	16	2	3

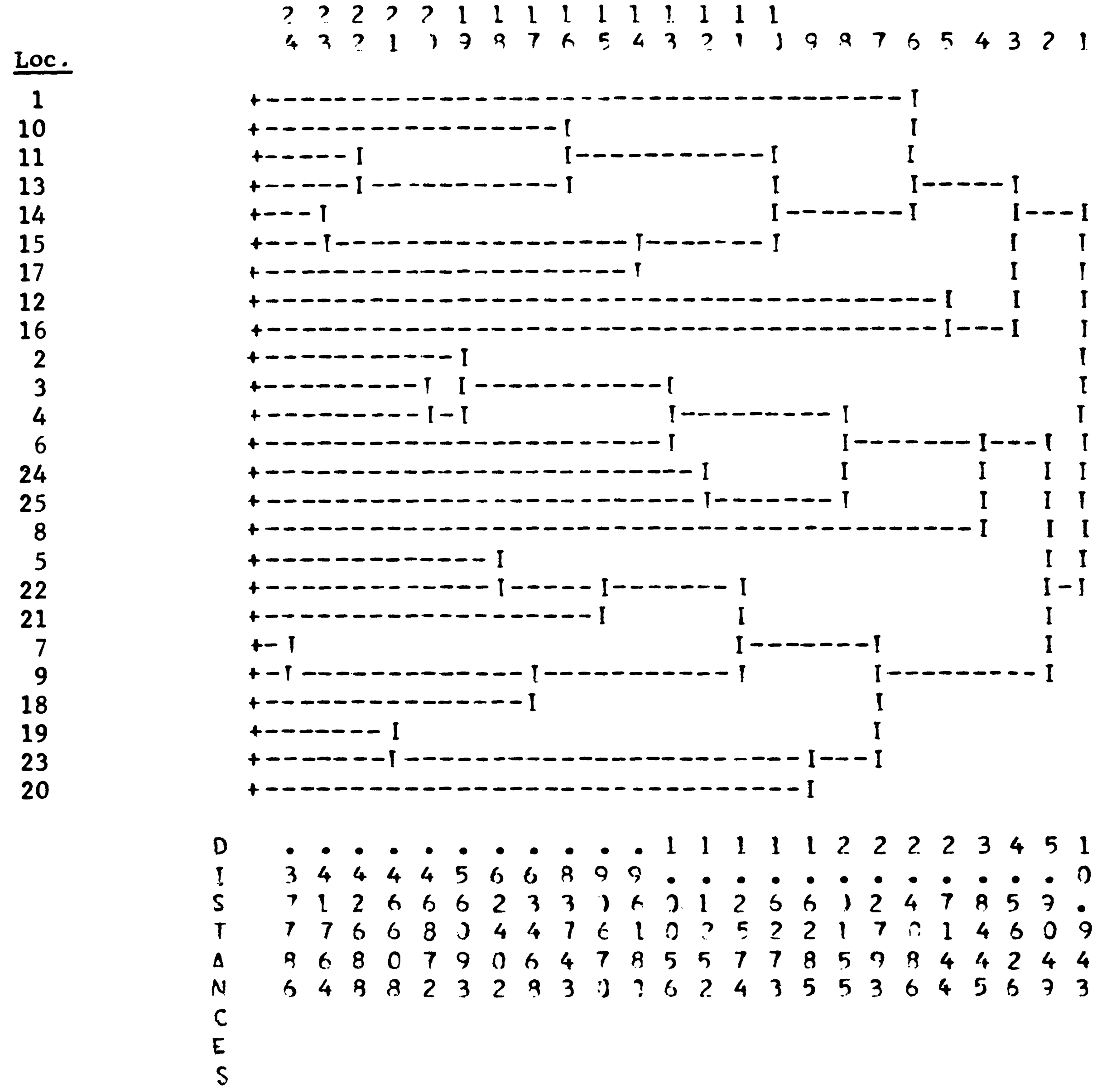
6	.97791										
24	.89003	1.3749									
25	.93191	1.6449	1.1252								
8	2.4862	2.5656	2.5462	2.4990							
5	.81932	1.3730	1.4478	1.9987	2.5707						
22	1.0996	1.9606	1.5344	2.0219	3.8205	.62402					
21	.74268	1.2941	1.5105	1.6263	3.1529	.93806	.73400				
7	1.0572	1.7114	2.0041	2.5677	3.6809	.88579	.62117	.55120			
9	.72046	1.5631	1.5923	2.0827	2.9409	.88217	1.0173	.84084	.37786		
18	.89365	2.0045	2.1285	2.4734	3.2751	.89325	.85146	1.0439	.65282	.48813	
19	.71352	1.9600	1.7215	1.8572	3.5722	1.5193	1.1572	1.0513	1.1035	1.0355	1.0041
23	1.2396	2.2455	2.0643	2.4219	4.4500	1.2964	.54656	.93973	.88494	1.4137	1.2304
20	2.0425	2.6340	3.2315	3.2210	4.9793	1.6460	1.2620	.93948	1.3427	2.1851	1.6836
Loc.	4	6	24	25	8	5	22	21	7	9	18

23	.46608	
20	1.6529	1.0230
Loc.	19	23

(continued)

APPENDIX D (continued).

Cluster Diagram, October



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16. ABSTRACT

This project was initiated to evaluate the water quality of northern Green Bay. Green Bay phytoplankton assemblages were characterized by high abundances and domination by taxa indicative of nutrient rich conditions. The most significant components of the communities were diatoms and cryptomonads in May and blue-green algae in August and October. Anacystis incerta, Rhodomonas minuta, microflagellates, Gloeocystis planctonica, and Cyclotella comensis were the most abundant taxa.

Two main regions of different water quality were determined by phytoplankton population and community analysis. These regions are approximately delineated as north and south of Chambers Island. Phytoplankton and physico-chemical indications of eutrophication were generally greater in the southern region. Local evidence of more severe perturbation was noted in Little Bay de Noc near the Escanaba River and Escanaba, and near the Menominee River. More naturally eutrophic shallow water communities were found in Big Bay de Noc and along the northwest shore of Green Bay. Less eutrophic conditions along the Lake Michigan interface with Green Bay probably resulted from dilution of Green Bay water due to exchange with Lake Michigan water. The exchange must result qualitatively in the export of nutrients and biological populations adapted to eutrophic conditions to Lake Michigan proper.

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